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FEASIBILITY STUDY FOR PLACEMENT OF VORTAC AT SEA

Final Report, Contract No. ARDS-499

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NOTICES

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ABSTRACT

The purpose of this study was to make a sound determination on the feasibility of various structures for positioning a VORTAC at sea. The primary contractual restraints on the project were that the study should be applicable to a single facility located at Ocean Station Charlie (latitude 52°45'N, longitude 35°30'W), that costs would be minimized, and that personnel safety would be paramount.

The study extended to the broad categories of operating vessels and moored platforms. The latter category was divided to include discussion of manned and unmanned craft, such as Liberty ships, submarines, seadromes and buoys.

Of major concern in keeping the study within the imposed limits were the problem of deep-water anchoring in the North Atlantic and the reliability of present VORTAC electronic systems in a continuous, infrequently maintained application. Other troublesome problems were crew comfort, reprovisioning techniques in a continual heavy-sea environment, and the structural design of the antenna complex. Recommended methods of deep-water mooring and of heavy-weather transfer operations have been discussed in detail, and suggested solutions outlined for each substantial difficulty encountered.

Each major proposal was evaluated with reference to a facility (such as the experimental model on the USCGC Androscoggin) aboard an ocean station ship. The recommended proposals, consistent with the prescribed constraints, are first, the placement of VORTAC aboard ocean station ships, and second, placement aboard special VORTAC trawlers. Should the scope of application of seaborne VORTAC be extended to a chain of ocean stations, an unmanned buoy would likely prove best—pending the availability of sufficiently reliable electronic systems and the proving of deep-water mooring techniques.

1
INTRODUCTION

This report summarizes a feasibility study to determine the best method for mounting a VORTAC at sea. The design of various platforms considered suitable and the modification of certain ships have been carried far enough to make certain of their feasibility, but the details of these designs or ship alterations are not specified in the report. It has been assumed that the platform or ship modification eventually selected would be engineered by a naval architecture and marine engineering design firm or by the firm which did the actual construction.

1.1. CONTRACT REQUIREMENTS

The contract required that the contractor should make a "scientifically sound, definitive determination as to the feasibility of the most suitable structure for positioning a VORTAC at sea." The platform and mooring, if mooring were required, were to be selected according to the results of a feasibility and economic study. Initial cost and operating cost were to be "paramount considerations." The solutions to the problems of maintaining VORTAC at sea were to be part of the work performed.

It was stated in the contract that the installation was to operate for periods at sea in a location to be selected by the Government. The initial location was anticipated to be latitude 52°45'N and longitude 35°30'W (Ocean Station Charlie). The proposed system was to be complete in all respects, "such as power sources, hazard lighting, transporting structure to and from sea station, etc." The installation was to be serviced at regular intervals "so that continuous operation is provided." The platform supporting the VORTAC was to accommodate technicians and other personnel if necessary.

The study was to include an engineering assessment of the physical and economic conditions involved and "consideration of alternate means of providing an ocean mount for VORTAC."

More detailed requirements, as stated in the contract, were the following:

1. Design Criteria. Analyze and determine imposed conditions such as physical size and weight of equipment for VORTAC, the limitations for operation of the equipment, the support facilities needed, and the maintenance requirements.
2. Seaway Conditions. Investigate from existing sources and summarize the physical conditions at the site including weather, tide, current, wave characteristics, ocean bottom conditions, depth of water to be encountered, etc.
3. Regulatory Bodies. Review and list the existing regulatory requirements for a floating mount.
4. Selection of Alternates. From the data compiled in steps one, two, and three, select at least four (4) mounts to be considered for evaluation. The mounts that will be considered shall include the following:
   (a) Manned Propelled Vessel
   (b) Anchored Armstrong Seadrome
   (c) Anchored Vessel (from the laid-up "Victory" fleet)
   (d) Anchored Buoy

   At this point of the work the Contractor was to review with Federal Aviation Agency personnel the reasons for the selection of the various alternate mounts.

5. Design. Preliminary design, sufficient for estimating purposes, shall be provided for the various alternate floating mounts selected. The design shall be sufficiently detailed to permit adequate cost and performance estimates to be made.
6. Estimates of Costs. Preliminary estimates shall be prepared for the initial cost and the operational cost of each of the selected alternate floating mounts.
7. Evaluation. Engineering evaluation shall be made of each of the selected alternates with regard to:
   (a) Economics - Initial, operating, and maintenance
   (b) Design - Suitability to meet performance criteria, and the Contractor shall determine the optimum overall method.

   The Government will furnish to the Contractor available technical information relative to the VORTAC for use in the performance of this contract.

1.2. GOVERNING ASSUMPTIONS

As a result of a review, called for by the contract, with personnel of the Federal Aviation Agency midway through the study, and on the basis of an interim report summarizing preliminary findings submitted at that time, certain assumptions which modified the contract were agreed upon to govern the remainder of the study. These assumptions are the following:

(a) Existing VORTAC antennas and electronic equipment will be used. Some redesigning of the antenna is permissible, but otherwise the platform should use existing equipment. One important result of this assumption is that the equipment needs frequent maintenance and cannot operate completely unattended.

(b) Only one location will be manned. This will be Ocean Station Charlie at latitude 52° 45'N and longitude 34°30'W.

(c) The Coast Guard will act as a support for the installation for everything except fueling, and for major supplies and repair items.

(d) Motion of the platform will not seriously affect the performance of the VORTAC.

(e) No function other than support for the VORTAC will be required of the sea platform.

(f) Cost must be minimized.

(g) The platform will have a useful life of five years.

(h) Limited outages of a total of 1 or 2% of the year are acceptable.

(i) All the proposed platforms will be compared to an installation of the VORTAC equipment on present Coast Guard cutters (i.e., in a manner similar to that on the USCGC *Androscoggin*). This installation requires placing the VORTAC equipment on six ships to provide complete coverage for one station. The cost of altering six ships, exclusive of the VORTAC equipment, totals $1,000,000.

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PHYSICAL CONDITIONS AT THE SITE

Ocean Station Charlie is located in the North Atlantic Ocean at latitude 52°45'N and longitude 34°30'W, and at a depth of 7200 feet. It is on the same latitude as central Ireland and southern Labrador, and somewhat east of the tip of Greenland.

2.1. CURRENT

It is well known that the Gulf Stream flows north from Florida along the coast of the United States until it reaches Cape Hatteras. It then swings away from Hatteras toward Great Britain and Norway. There is a back or eddying flow along the northern United States, Nova Scotia, and Labrador. This flow is the Labrador Current, which has a strong influence on the weather of the northeastern United States and Canada. Ocean Station Charlie is located at a juncture of the Labrador Current and the Gulf Stream where the predominant direction of flow is northeast. The station is generally in the Labrador Current rather than in the Gulf Stream.

In January the current is predominantly in the northeasterly direction, but there are times when it sets in all of the other directions. The drift averages about ten miles per day, but there can be wide variations from place to place. February and March show essentially the same characteristics as January, although the drift drops to about six miles per day in March. By May the drift drops another one or two miles per day, but the set is essentially the same. July shows little decrease in the drift, but the set becomes more nearly isotropic. The most frequent current in the due westerly direction occurs in September; however, the general character is similar to that of July. Both July and September have about the same drift as May. By December the current approaches the set and drift that it had in January, although it is not showing the northeastern set as predominantly. The drift rises a little, but is not yet at January levels.

2.2. ICE

In general, the North Atlantic is free of ice. That which does exist is usually near the shore, and not prevalent until one reaches latitude of 60° north. The only ice that might be pres-

ent at Ocean Station Charlie would be icebergs and growlers. The ice chart for January shows no floating ice in the vicinity. In fact, a survey of the monthly ice charts indicates that ice is most likely to appear at Charlie in the Spring and early summer, with June being the most likely month. The writers believe that ice will not present a serious problem at Ocean Station Charlie.

2.3. SEA TEMPERATURES

The sea water temperatures at Ocean Station Charlie do not show wide variations. As would be expected, the temperature varies from a low of about 44°F in January to a high of 55°F in August. Some of the change is probably caused by shifting of the ocean currents.

2.4. AIR TEMPERATURES AND WINDS

The mean monthly air temperatures follow the sea temperatures closely. January has a mean monthly air temperature of 45°F, whereas August has a mean of about 57°F. A check against the water temperature shows that the mean air temperatures do not vary more than two or three degrees from the water temperature. In this area of the ocean the weather can be quite uncomfortable, but extremes of heat and cold are uncommon. Also the diurnal temperature variation is small.

The following discussion of wind activity is based on Table I, a combining of the Beaufort and U. S. Weather Bureau wind scales.

TABLE I. WIND SCALE

Beaufort Number	Seaman's Description	U. S. Weather Bureau	Wind Velocity (mph)
0	Calm	Light	less than 1
1	Light air		1-3
2	Light breeze		4-6
3	Gentle breeze	Gentle	7-10
4	Moderate breeze	Moderate	11-16
5	Fresh breeze	Fresh	17-21
6	Strong breeze	Strong	22-27
7	Moderate gale		28-33
8	Fresh gale	Gale	34-40
9	Strong gale		41-47
10	Whole gale	Whole Gale	48-55
11	Storm		56-65
12	Hurricane	Hurricane	above 65

Winds generally tend to blow from west to east in the North Atlantic. As might be expected, they are stronger in winter than in summer. At Ocean Station Charlie the monthly pilot charts show the most frequent wind direction to be from west to east, and further indicate that in winter, the average number on the Beaufort wind scale is 6. The chart also shows that in the region of Charlie, during the month of February, gales occur over 20% of the time. Ocean Station Charlie lies in the path of many severe storms which occur during this month, and in fact, the whole year.

By August the average wind velocity has dropped to about Beaufort Number 4 or less. The distribution of directions remains predominantly west to east. The gale frequency has dropped from over 20% to about 5%.

2.5. SEA AND SWELL

The directions of the sea and swell generally correspond to the direction of the winds; that is, the predominant direction is from west to east. The sea and swell chart for February shows that both the sea and the swell are high more than 50% of the time. Although the sea and swell take the same direction about an equal number of times in a year, they are not necessarily concurrent at any given time. By August the predominant direction of the sea and swell is from the northwest, although the frequency from the west is nearly as large. The frequency of high seas has dropped by this time to about 30%.

The northern part of the North Atlantic is least often rough in July and August because the winds of gale force (Beaufort Numbers 6 to 8, or stronger) are least frequent then. It is only to the northward of the general latitudes of southern Newfoundland and of southern Britain that seas higher than 8 feet have been reported as often, even, as 10% of the time for August. The frequency distribution for swells of different heights over the North Atlantic in summer is similar to the frequency distribution for seas. It is only to the northward of about latitude 50^{o} N that swells higher than 12 feet are reported for August with a frequency as great as 20%, while the most extensive area where the swell is described as low (1 to 6 feet) in more than 60% of the reports for that month is along a belt of variable winds in the midlatitudes. But the differences in detail between the distribution of swells and of seas are enough to require consideration. A high swell is reported with 9 to 20% frequency in August from Newfoundland right across the Atlantic to the coast of Europe (Scotland to Southern Spain), where a high sea is decidedly less common. The increasingly stormy weather of autumn in high latitudes continues through the winter and results in an increase in the average frequency of high seas to 50 or 60% and more between Newfoundland, Greenland, and the coasts of northern Europe. This storminess also causes so wide an expansion from summer to late winter, throughout the re-

gion where high seas are encountered for more than a very small part of the time, that more than 20% of the reports for January and February combined have classed the sea as high (over 8 feet) throughout the whole of the North Atlantic down to latitudes 30° to 35°N, except for the areas along the coasts of southern Spain and of northwest Africa on the one side, and along the northeastern United States on the other.

This description gives only a very misleading picture of the actual fierceness of the sea that ships often encounter in high latitudes of the North Atlantic during winter gales, for no one who has made many winter crossings during the stormy season would class an 8- or 9-foot sea as a high one for that part of the ocean at that time. Actually, during 13% of the time, waves of 20 feet or higher have been reported by ships sailing between Newfoundland and England throughout the year, a turbulence for which the storms of winter are no doubt chiefly responsible. And waves more than 40 feet high have been reliably reported, not only along this belt, but even as far south as the Azores, during winter gales of unusual severity. Current information does not touch on this point; however, it is certainly unusual for the sea to rise much higher than about 15 feet anywhere in the western Atlantic south of Newfoundland, unless during exceptionally severe gales.

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3
TECHNICAL ASPECTS OF THE PLATFORMS CONSIDERED

This section of the report is intended to provide sufficient technical information about the various platforms considered for supporting VORTAC at Ocean Station Charlie to acquaint the

reader with the writers' concept of the installation and structure and some of the problems their use would entail. The descriptions of the platforms therefore vary greatly in degree of detail, more information being presented when it is felt that the platform itself is new or unique and most aspects of its configuration and operation need to be understood, and less when only one aspect of an otherwise familiar or easily identifiable platform needs clarification. Other parts of the section treat considerations pertinent to the VORTAC antennas and electronic equipment and regulatory requirements.

3.1. DESCRIPTIONS OF PLATFORMS CONSIDERED

3.1.1. LIBERTY SHIP. One way to mount a VORTAC at sea is to use a full-size ship. Since World War II Liberty ships are the type easiest to obtain, the Study has assumed the obtainability of a Liberty ship. Other types, such as Victory ships, might be available, in which case they should be used. There is a wide variation in the condition of Liberty ships. It is recommended that one which is, or has recently been, "in class" should be obtained if possible. ("In class" means that the ship has been certified as seaworthy by one of the classification societies such as the American Bureau of Shipping.) If an "in class" ship cannot be obtained, an effort should be made to obtain a ship which has been strapped. (Strapping is the adding of extra steel to the hull to increase the strength.) Any "in class" ship will be strapped.

In considering the Liberty ship as a platform for VORTAC it has been assumed that the ship has no propulsive capability. The Liberty ship has not been considered as an operational ship for the following reasons:

(a) The propulsive plant probably would require considerable reconditioning to restore it to operating condition.

(b) The propulsive plant of the ship is ill suited to the type of operation required by this service. In fact, the entire ship would require too large a crew to make its operation economical. It is believed that a specially designed, newly built ship or small trawler would prove more economical in the long run. Some further discussion on this point will be found under the discussion of the new ship.

Since the propulsion would not be used, it proposed that the remainder of the existing machinery not be used except for possibly the sanitary and ballast systems. Steam for these systems would be supplied by a newly installed package boiler. The new machinery which would probably be necessary is as follows:

2 150-kw four-cycle, six-cylinder, precombustion-chamber diesel-generator sets

2 12,000-cfm fans

2 shell- and tube-type heat exchangers

1 32-volt electric starter for diesel
1 6000-cfm preheater
1 emergency fire pump, 500 gpm, 125 psig
1 550,000-BTU per-hour steam generator
1 2000-gallons-per-day flash-type evaporator
2 water-jacket pumps, 100 gpm, 40 psig
2 sea water pumps, 100 gpm, 30 psig
1 brine overboard pump, 70 gpm, 20 psig
1 distillate pump, 3 gpm, 30 psig
1 salt-water drain pump, 5 gpm, 20 psig
1 salt-water feed pump, 70 gpm, 50 psig
1 refrigeration unit, 1.5 tons per day
1 emergency standby 50-kw diesel electric set
1 fresh-water pump, 30 gpm, 50 psig
1 fuel-oil transfer pump (screw type), 50 gpm, 250 psig

All of the new machinery would be installed on the second deck. This would require the decking-over of the present engine and boiler casings to form a strong enough platform to support the machinery. The propeller and shafting would be removed, and the stern tube would be blanked off. Figure 1 shows an inboard profile and deck plan of the modified ship. Other modifications to the ship would require the removal of the uppermost deck, the bridge, and the stack. All but one king post could be removed. The one remaining king post could be used to support a boom and the TACAN antenna. It is proposed that the VOR and TACAN antennas be separated, as on the USCGC Androscoggin. Additional modifications would include complete renovation of the living quarters to accommodate eight men. Part of this would be the installation of a new ventilation system which could supply the VORTAC equipment room as well. This room should be located immediately under the existing bridge deck, or at the level of the present boat deck. The hull would undoubtedly require some reconditioning and painting. This type of installation would require no new antenna design.

Because the Liberty ship rolls heavily, anti-rolling tanks might be a sound investment. These should be similar to those installed on the Pvt. Joe E. Mann. The tanks should have means for manual draining and filling to provide a means of tuning them. Under relatively stable sea conditions it would be possible to make adjustments to optimize the effectiveness of the tanks. It is estimated that the cost of the anti-rolling tanks for the Liberty ship would be $25,000, but this sum does not include engineering costs.

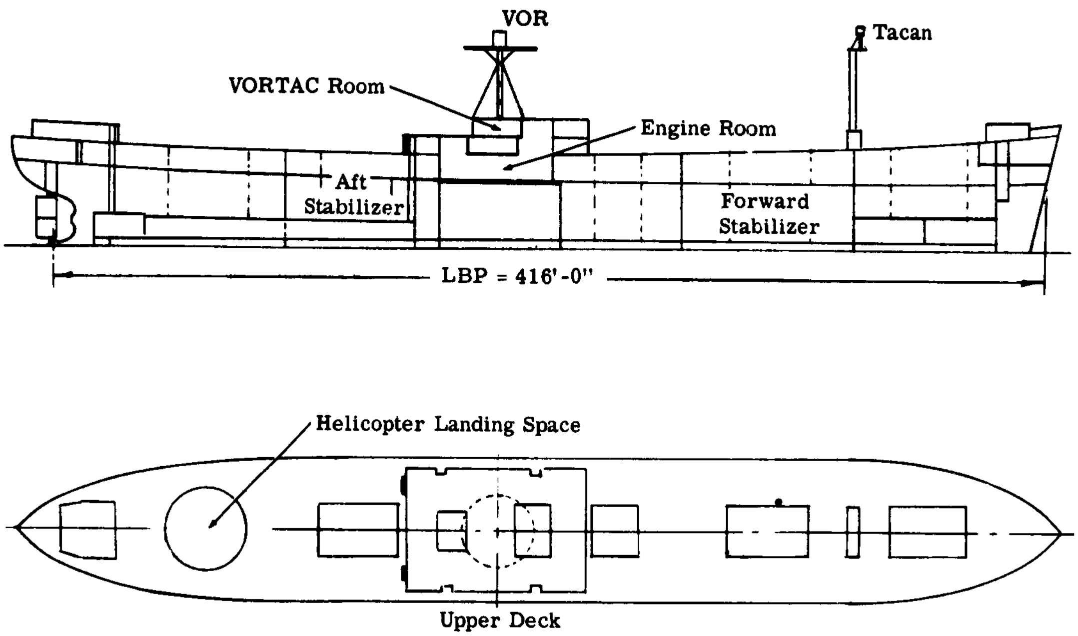


FIGURE 1. PLAN AND INBOARD PROFILE OF MODIFIED LIBERTY SHIP

Of all the platforms proposed, the Liberty ship presents the most serious mooring problem. Not only will it require a very costly mooring, but some development will be necessary to establish the mooring method. This will be discussed further under the section on mooring problems.

A helicopter platform could be constructed at the stern of the Liberty ship. This would be intended primarily as a safety measure and not for the transfer of men and supplies.

3.1.2. CUT LIBERTY. In order to reduce the wind loads and therefore the mooring problems, the full-size Liberty could be cut so that only 85 feet of the center section remained. A sketch of this platform is shown in Figure 2. As in the case of the full-size Liberty ship, the stack, bridge, and uppermost deck have been removed. All of the king posts are gone, and the VOR and TACAN antennas are mounted together. Flat plates are welded on fore and aft to form a blunt bow and stern. The new machinery and its location would be the same as for the full-size Liberty ship, and the living quarters and VORTAC equipment room would be similar.

This cut Liberty ship would still be more difficult to moor than a buoy-like platform designed to perform the same function. The displacement would be about one third of that of

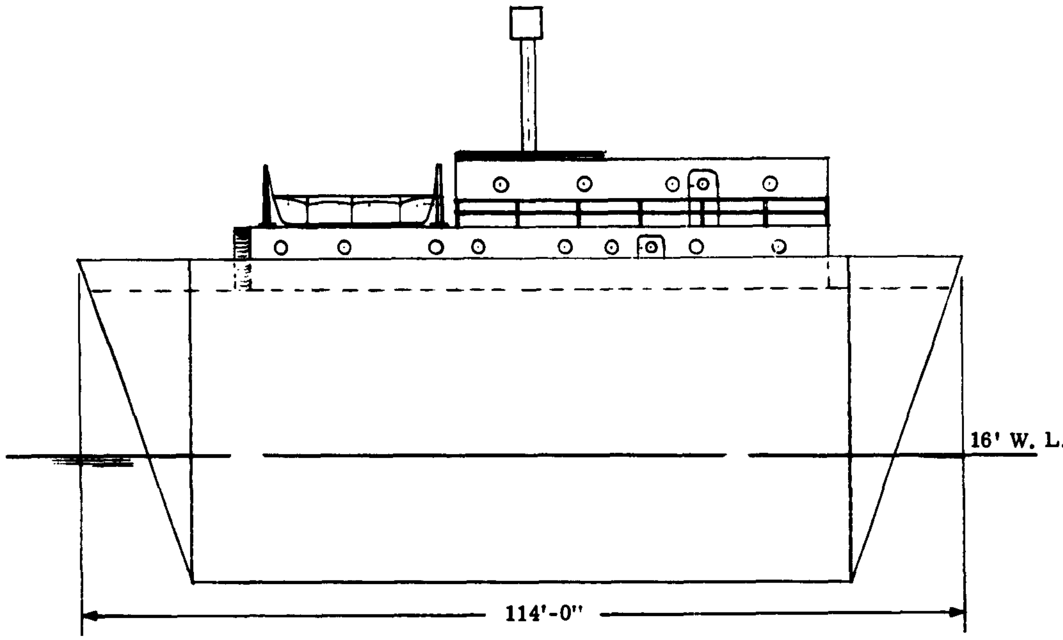


FIGURE 2. CUT LIBERTY SHIP CONCEPT

the full Liberty ship, or about 2400 long tons. The projected area above the waterline would remain as large because the full Liberty ship, if moored to a buoy and allowed to stream, would normally present only its bow to the wind.

The cost of the modification considered necessary is actually larger than that for the full Liberty ship because of the fabrication of the new ends. The motion characteristics would not be appreciably improved and could quite possibly be worsened.

3.1.3. MANNED BUOY. Figures 3 and 4 show sketches of one concept of a manned buoy. This buoy would be shaped like a spoked wheel with four wide spokes, a large hub, and a large rim. The overall diameter would be 60 feet. The overall depth of the hull would be 30 feet, the freeboard 24 feet.

The 32-foot-diameter hub of the wheel would be the counterpoise for the VORTAC antenna. The antenna would project from the center in the fashion of a wheel axle and be 24 feet high. The spaces between the spokes would be used to admit light, much as a center courtyard of a building admits light to the windows. These spaces would also allow water to drain from the counterpoise. The rim of the buoy would contain tanks which hold fuel and ballast and also

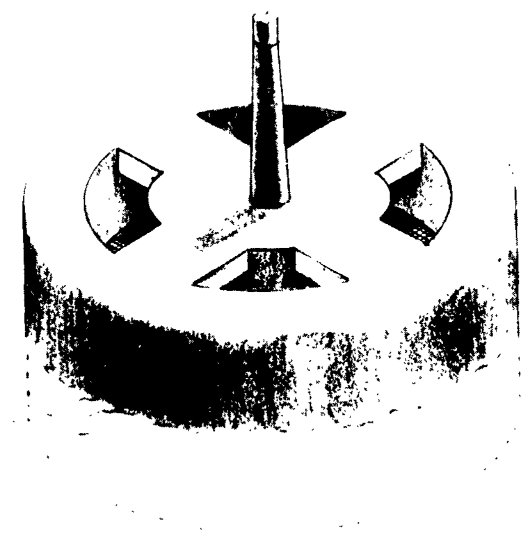


FIGURE 3. ROUND MANNED BUOY

provide collision protection for the men and machinery, all located in the hub section. The buoy would have three decks, arranged as shown in Figure 4. The lowest deck would contain the machinery, which is similar, except for minor details, to that described for the Liberty ship. Accommodations would be provided for eight men, as shown.

The buoy would be easier to moor than the Liberty ship. Like the other manned platforms, the manned buoy would insure regular and prompt maintenance of the electronic equipment. But it would also be uncomfortable for the crew. Its motions would often be of short duration, and therefore the accelerations could become relatively high. Because of its size it should follow the wave slope closely, and the magnitude of the motions should not be excessive. However, obtaining a crew would probably be difficult.

As in the case of the Liberty ship and cut Liberty ship, it is assumed that personnel would be regularly rotated. It is further assumed that the Coast Guard cutters assigned to Ocean Station Charlie would act as support vessels by transporting some supplies and the personnel.

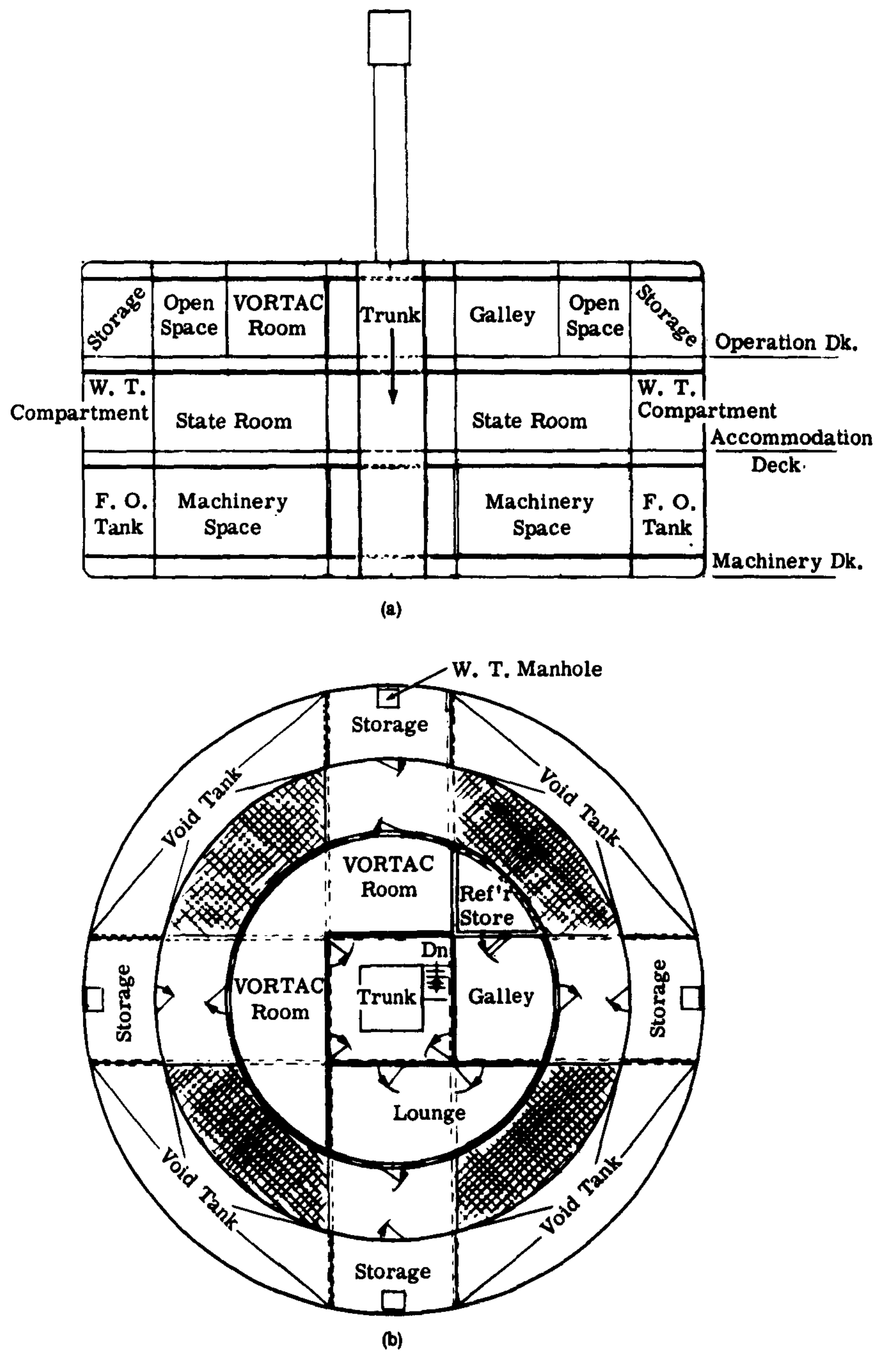


FIGURE 4. DETAILS OF MANNED BUOY. (a) Inboard profile. (b) Operation deck.

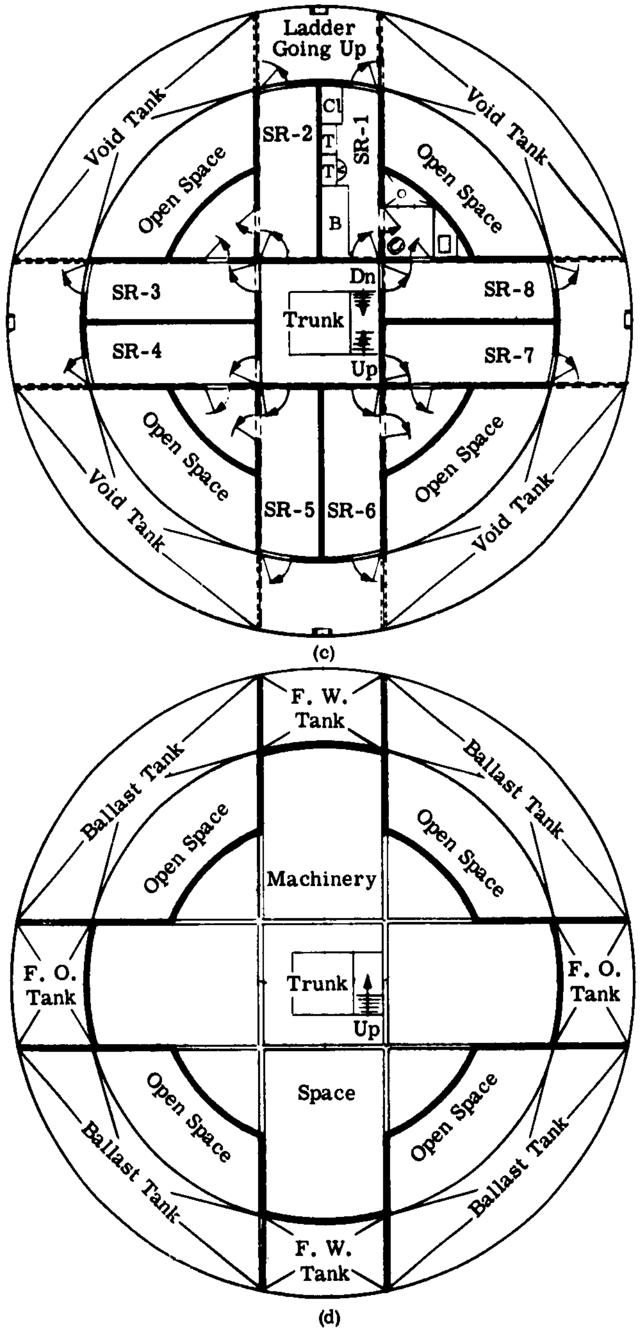


FIGURE 4. (Continued) (c) Accommodation deck. (d) Machinery deck.

This means that the crew would be rotated according to the schedule of the Coast Guard cutters. Fuel and large supply items would be transported by other means.

Since the crew would be rotated, men would have to be transferred from ship to buoy. This is a disadvantage of all the manned, moored platforms. The full cooperation of the Coast Guard would be necessary since the returning cutter would on occasion be required to wait several days before it would be able to transfer the personnel. Major replenishment of stores, parts, water, and other items could for the most part take place in summer when the weather is more moderate.

It is anticipated that some redesigning of the antenna would be necessary. Since the top of the manned buoy is just 24 feet above the nominal waterline, it is believed that there might be a few times when it would take solid water aboard. This would create severe loads on the antenna structure which available units are not capable of withstanding. The antenna could be designed to be withdrawn into the trunk beneath it at such times, and for purposes of maintenance.

The cost of the designing, engineering, and construction of such a platform would be a major factor in determining its possible selection, since it would be at least twice that for the full Liberty ship.

3.1.4. SMALL OPERATING SHIP. Next to installation on a Coast Guard cutter, it is believed that placing a VORTAC on a specially built ship would involve the fewest uncertainties. One of the prime requirements for this type of ship is seaworthiness. For a preliminary investigation it has been assumed that the ship for VORTAC could be similar to oceanographic research vessels. There would, however, be several important differences. The VORTAC ship would have modest power requirements and could be single-screw. The VORTAC ship could even have an economical, low-power engine for use while on station and a light-weight, high-speed engine for moving to and from the station.

The freeboard requirements of the two ships might differ. Oceanographic vessels require some low freeboard, generally aft, for the bringing aboard of marine samples. Since the VORTAC ship would not have this requirement, the freeboard could be determined entirely on the basis of seaworthiness.

The VORTAC ship should probably need a crew of twelve in addition to the personnel for operating and maintaining the VORTAC. Thus the crew could total fifteen. The VORTAC ship would require less living and work space than an oceanographic ship. Figure 5 shows what is basically an oceanographic vessel of 175 feet. The oceanographic ship shown has been modified to meet the requirements stemming from placing VORTAC aboard. It would also be possible

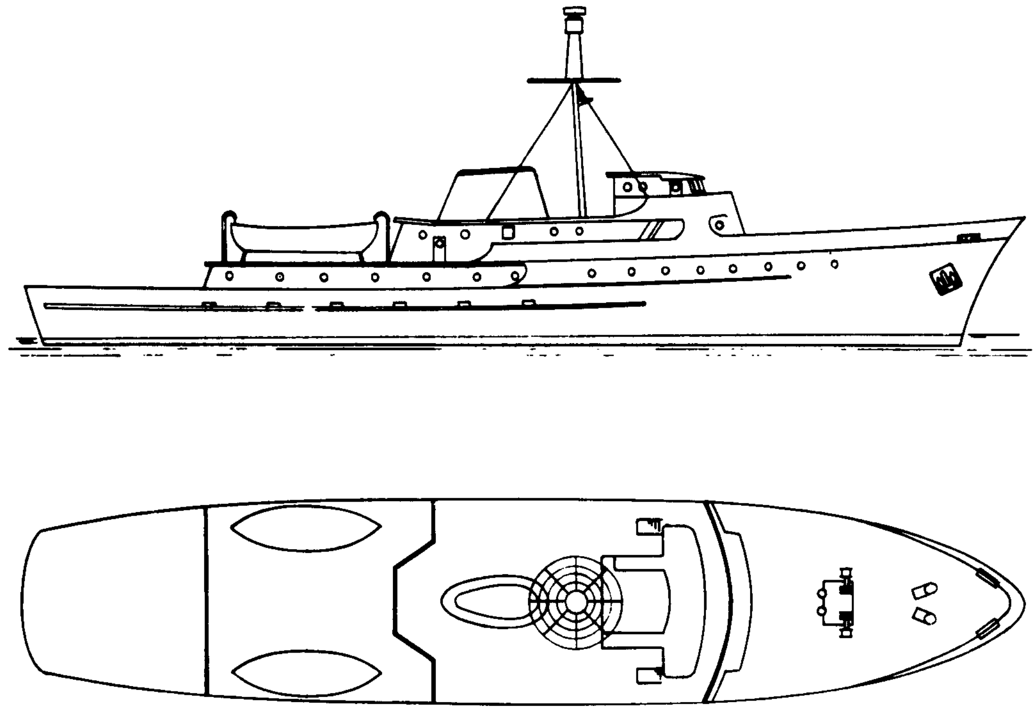


FIGURE 5. MODIFIED OCEANOGRAPHIC RESEARCH VESSEL

to modify other existing ships, such as trawlers. Large trawlers range from 130 to 200 feet in length. Many more of this size are built abroad than in the United States. Figure 6 shows a 200-foot trawler, which would be an excellent ship to modify for VORTAC service. Like an oceanographic ship, the trawler has low freeboard to allow the catch and fishing gear to be brought aboard, as shown in the figure. A trawler could be modified to increase the freeboard amidships since the low freeboard would be a disadvantage for VORTAC service, at least in the North Atlantic at Ocean Station Charlie.

It is believed that the minimum cost of a new ship designed and built for VORTAC installation would be $1,250,000. This assumes that the VORTAC ship would be well equipped. It is believed that an operating trawler could be bought for $225,000. Some quotations solicited actually ran as low as $20,000, but it could be expected that a ship at this lower figure would require considerable costly reconditioning. In the long run the latter alternative might prove to be the better, since the trawler could be easily fitted out to meet VORTAC requirements.

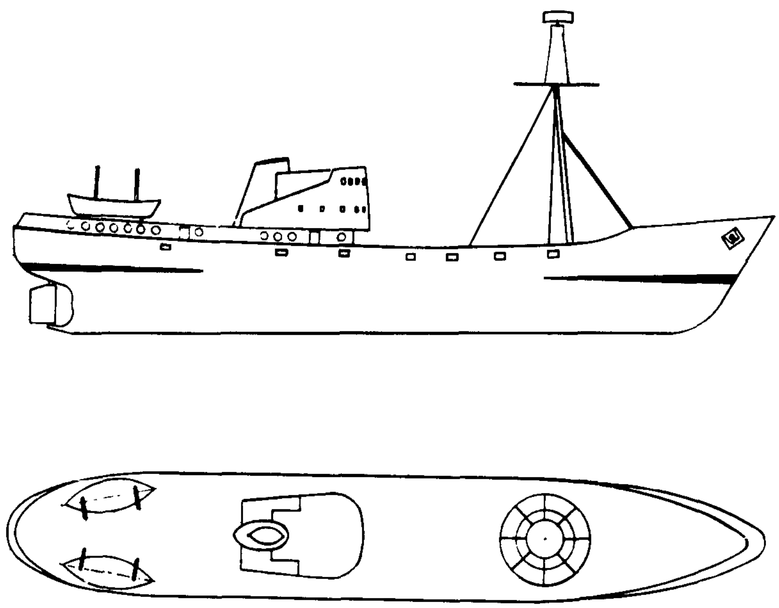


FIGURE 6. MODIFIED TRAWLER

The principal advantages of a small operating ship for this task are that the VORTAC equipment may on occasion need major servicing, and as the ship would frequently return to base, especially competent repair and maintenance personnel would be available. The use of the specially designed ship or converted trawler would also eliminate the uncertainties and costs of mooring. Either could utilize presently available antennas and have the ability to shift position readily if necessary. A trawler contrasts with a large ship in that it has a lower first cost, a much lower fuel bill, and, most importantly, a smaller crew.

In order to keep one ship on station, at least two operating ships would be required. Thus the small-ship concept is the only one described which would require two units to maintain one on station. Operating costs would accordingly be high. Because of the need for a relatively large crew of fifteen for each ship, as compared to a maximum of eight needed for the moored but manned stations, the annual operating costs would be appreciably higher than for any other platform considered. There are certain other considerations that cannot easily be evaluated. It is probable that some government official might ask why the FAA wants to operate a second ship at Ocean Station Charlie when the Coast Guard is already there. We do not know how important this consideration might be.

Since this small-ship concept assumes either that a ship will be designed specifically for VORTAC or that a suitable existing ship will be converted, the machinery installation and the general arrangements would require little, if any alteration. The crew members, exclusive of the FAA technicians to handle the VORTAC equipment, could presumably be recruited from among regular seamen. The ship would not be a comfortable one in very rough weather, but it would be relatively safe and could maneuver, when necessary, much as the Coast Guard cutters at Ocean Station Charlie do.

3.1.5. UNMANNED BUOY. The possibility of placing the VORTAC at sea, with no crew actually aboard the platform, has a great many advantages. Foremost among these are that the size and complexity of the platform, and hence its initial cost, can be greatly reduced. The fact that quarters and many of the services a crew would require are not needed could result in a truly utilitarian arrangement of the components necessary to allow the VORTAC to operate. Further, the comfort of the crew, with respect to the motions of the platform, is no longer a very important factor, and the safety of the entire scheme is not as critical.

The concept involved in an unmanned platform would be that several (probably three, two electronics specialists and one motor mechanic) FAA personnel could be sent to Ocean Station Charlie aboard each Coast Guard cutter which took up station there. They would remain aboard the cutter throughout its stay, and would eat and sleep in quarters arranged for by the FAA—much as weathermen from the U. S. Weather Bureau do at present. They would return to base with the cutter when the patrol was completed, being replaced by three other technicians aboard the cutter coming on station. These technicians could assist the Coast Guard whenever possible, but would spend most of their time doing such repair or maintenance as would be possible on FAA equipment (modules of electronic equipment or other relatively small subassemblies they could bring from the unmanned platform to the cutter). It would be routine for them to board the platform perhaps as often as every other day, weather permitting. While aboard they would also engage in feasible maintenance and repair work, and stay aboard as long as the captain of the cutter and their own comfort permitted. If the weather were good there should be no reason why they could not stay aboard overnight.

These technicians would also be available to board the platform at any indication that the equipment aboard was malfunctioning. Monitors of the VORTAC equipment could be placed aboard the cutter, or at least some scheme could be worked out to allow those on the cutter to know it was not doing its job correctly. Similarly, either by visual means (trouble lights on the platform, for instance) or by some telemetering radio device, the technicians aboard the cutter could be informed that the electrical-supply system, the fuel-oil system, or others were not operating properly. The technicians could presumably remedy the malfunction by cutting in a

duplicate system manually after diagnosing the trouble, repairing whatever was wrong, and again returning to the cutter. In any case, men aboard the platform could make necessary decisions on the basis of the trouble they found.

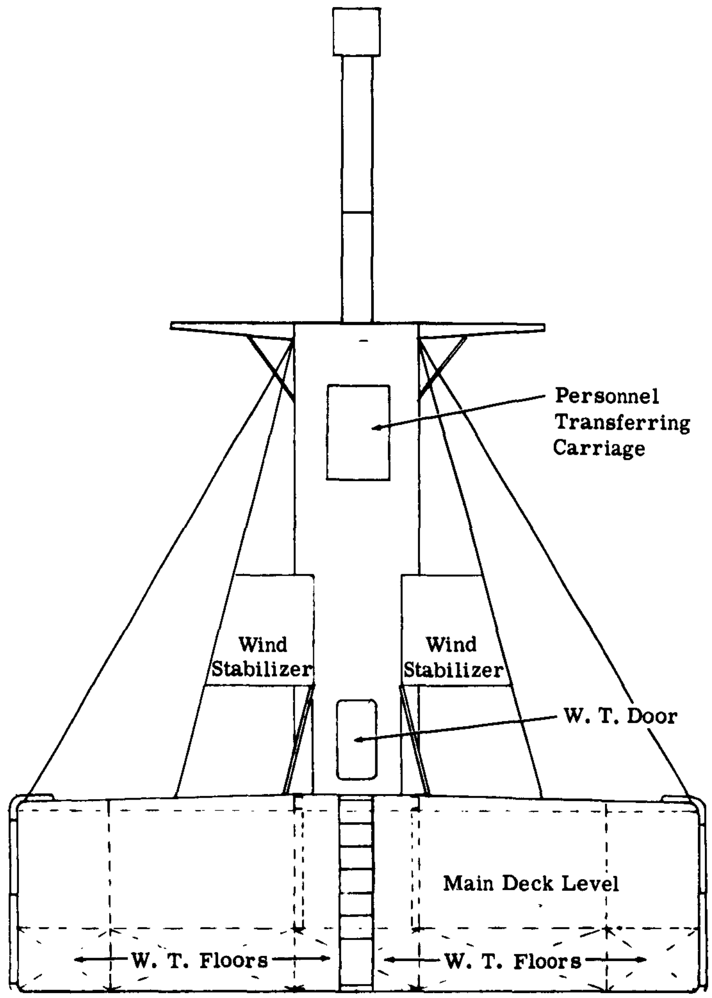
The most feasible of the unmanned platforms would be what we have come to call the unmanned buoy. A sample design of such a platform measures 44 feet in diameter and over 42 feet from the bottom shell to the counterpoise. The general arrangement could be as shown in Figure 7. The 44-foot-diameter hull would be 12 feet deep at the side, and the deck would rise another 6 inches toward its center. A tower 8 feet in diameter would extend upward from the deck some 30 feet. The top of this tower would support the counterpoise and the VOR and TACAN antennas. The main hull would be flat-bottomed and could presumably be built on skids and launched at almost any shipyard, and later drydocked, with relative ease.

Surrounding an inner space about 32 feet in diameter would be eight void tanks, four of which would be accessible from the inner space and hence usable for storage. These tanks would be incorporated into the design to gain waterplane area and to allow for collision damage. Although they are only 6 feet wide, they could provide some degree of safety were the outer shell to be pierced by the bow of a cutter or a tug working alongside. The flooding of any one of the tanks would not cause the buoy to be lost. A partial inner bottom would be incorporated into the design, and four quadrant-shaped double-bottom tanks 4 feet deep would be used for fuel oil. These tanks would extend to the outer shell and would be filled with salt water if the entire depth of the side shell at certain points were opened in a collision.

It should be noted that this arrangement was generally the result of the structural plan decided upon as most reasonable to provide adequate strength to the hull. Four heavy deck girders and four double-bottom girders (floors), together with web frames and pillars, would constitute four truss-like assemblies, which would cross so as to form an 8-foot center square under the tower. The ends of these assemblies would also provide support for eight vertical timber fenders which would protect the outer shell when a ship was tied up alongside.

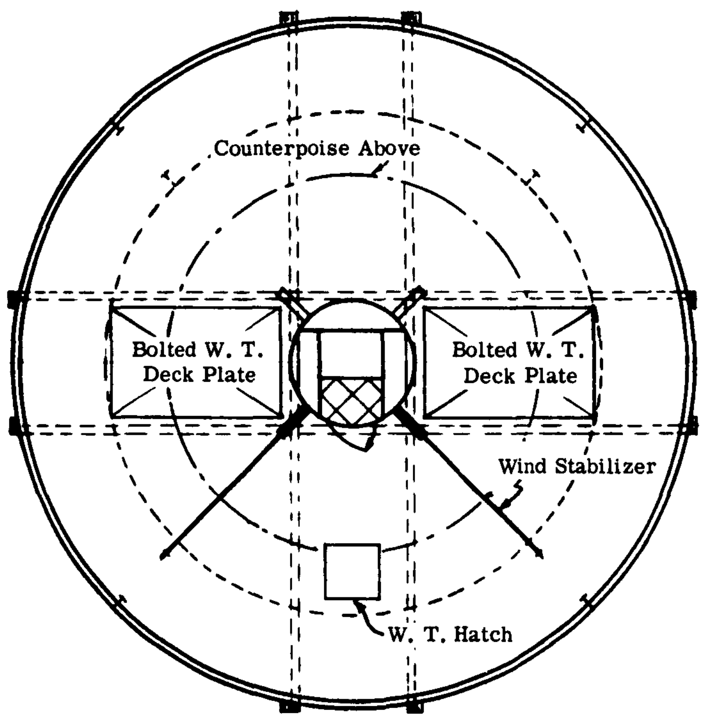
Two large diesel generators would be placed on foundations attached to and incorporating the bottom girders and bottom shell. This would allow the heaviest equipment aboard to be set low in the hull. Other heavy equipment, including two winches needed for the transfer scheme discussed later, could also be placed on the remainder of the uncovered double-bottom space and removable grating fitted around it. Control panels, small pumps, and the myriad other engine-room equipment would then be arranged on the plated tank top.

The inner 32-foot-diameter space could be subdivided by two light bulkheads. One of these would separate the VORTAC equipment from the engine room, whereas the other would isolate



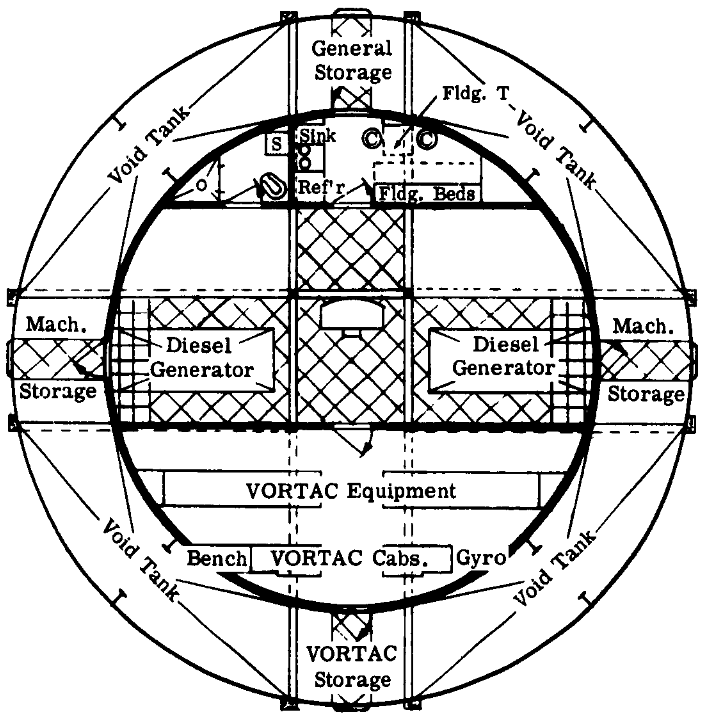
(a)

FIGURE 7. DETAILS OF UNMANNED BUOY. (a) Inboard profile.



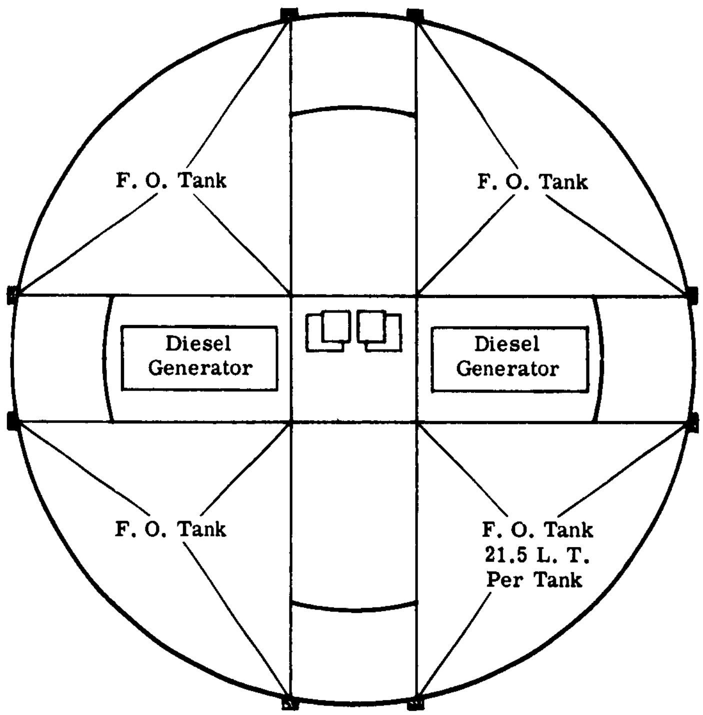
(b)

FIGURE 7. (Continued) (b) Weather deck.



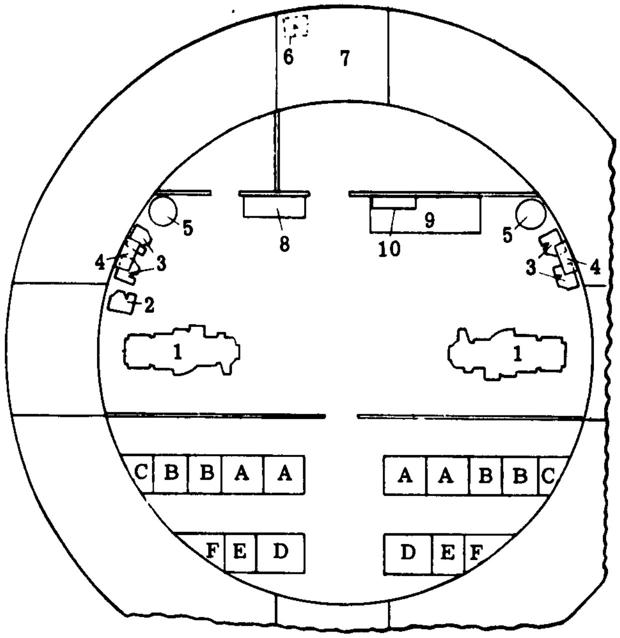
(c)

FIGURE 7. (Continued) (c) Main deck.



(d)

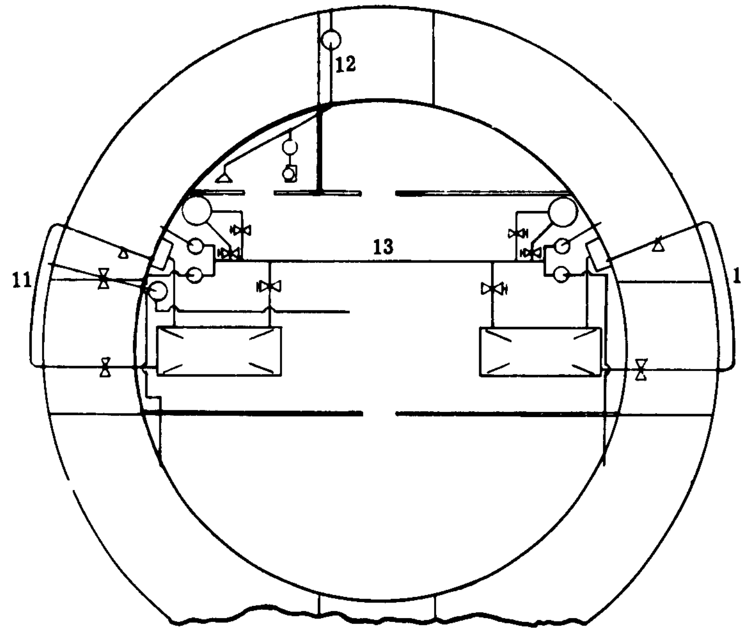
FIGURE 7. (Continued) (d) Bottom level.



1. Diesel Generator
2. Bilge Pump
3. Fuel Oil Transfer Pump
4. Cooling System Surge Tank
5. Day Tank
6. Salt Water Sanitary Pump
7. Fresh Water Tank
8. Generator Controls
9. Work Bench
10. Light Panel
11. Diesel Cooling System
12. Sanitary System
13. Fuel Oil Transfer System

A. TACAN Beacon
B. TACAN Monitor
C. Locker
D. VOR Cabinets
E. TACAN Cabinets
F. Bench

(e)



(f)

FIGURE 7. (Continued) (e) Machinery and VORTAC layout. (f) Piping schematic

what may be termed living space. The VORTAC space would be large enough to accommodate two dual systems. A possible arrangement of the equipment is shown in Figure 7(d). Bench space and room for whatever compasses (gyro or magnetic) were to be used, as well as sufficient clearance between the various units to facilitate working on them, would be provided. In this area the double bottom would be decked over completely, but the 8-foot-wide space between the bottom girders could be used for storage if access were provided in the tank-top plating. The one outboard tank adjacent to this space could also be used for storage, with access through a regular watertight door. The deck could be covered with tile if desired, and the bulkheads overhead, as well as all those in the inner space, lined with cork or other suitable material.

The living space would consist of two compartments. One would be a head, accessible directly from the engine room, and the other would contain a Pullman-type galley and two folding bunks. Although this would not be entirely necessary, we believe that the space required and the extra cost of a sanitary system and the few items of furniture would be justified during the buoy's possible early trial operations and in the event the technicians might wish to stay aboard for a day or two at Ocean Station Charlie. Some emergency food supplies would have to be kept aboard in any case, and the standard refrigerator-freezer is probably the least expensive manner in which this can be done short of using army-type rations.

The weather-deck plating of the buoy could be arranged so that four flat, sloping areas would be provided. The two of these over the diesel generators could be fitted with plates, removable in case a generator had to be replaced, bolted to the deck girders. In calm weather, this could even be done on station by a cargo ship with an adequate boom. A regular watertight hatch with a coaming could also be fitted over the VORTAC space. This would make it possible for entire cabinets of the VORTAC equipment (or other relatively small pieces of equipment) to be taken aboard the Coast Guard cutter if it could come alongside and rig a light boom. A light portable stiff leg with boom (normally stored inside the tower) could also be placed in deck fittings near the hatch, and used to lift supplies or equipment from inside the buoy to a small boat alongside, or from the small boat to the buoy.

The tower of the buoy would serve several purposes aside from placing the counterpoise and antennas sufficiently high above the waterline to preclude their being damaged or their operation being impaired by high seas. The intake and exhaust ducts of two blower systems would be placed some distance up the tower (the engine exhausts would be in the side of the main hull so as not to contaminate the ventilation intake air). The tower would also provide access to the buoy by a possible transfer scheme discussed below, and by means of a watertight door at its base. This watertight door would be the usual means by which personnel would

enter the buoy from its deck after having been transferred to the buoy by small boat. The tower would be guyed by means of seven heavy (2 inches in diameter or greater) wire cables fitted with turnbuckles and running from the deck, at the periphery of the main hull, to the base of the counterpoise. These would be 45 degrees apart. The absence of an eighth cable would allow access to the buoy by the tower transfer scheme. This location would be kept downwind by means of two sail-like wind stabilizers fitted from the tower to the two adjacent guy lines. The watertight door at the tower's base, and the deck hatch, would also be at this downwind location (assuming that small boats would approach the buoy on this side).

Although it does not seem appropriate to include here the plating thicknesses, machinery weights, all dimensions and centers, etc., that were used in various trial calculations to determine the location of the center of gravity of the buoy in various loaded conditions (as well as for cost estimates, stability analyses, flooding considerations, etc.), it would be inherent in the design that the buoy would have its center of gravity below its center of buoyancy. This would require some lead ballast distributed over the bottom shell and very careful consideration of the weight of any items or structure, particularly in the tower. The buoy would be stable over a large range of stability (angle of inclination), wherever the center of gravity happened to be, because of the relatively large waterplane provided, but it is conceivable that if the sea were extremely rough, water on the deck could cause too much of this waterplane to be lost. There would be no question regarding satisfactory stability of the buoy if the center of gravity were kept below the center of buoyancy. The draft would be about 6 feet, depending upon the amount of fuel oil aboard, and the displacement from 250 to 300 long tons. A total capacity for over 80 long tons of fuel oil would be provided, and it would be desirable to keep the minimum level at perhaps 20 tons.

The major machinery aboard the buoy would be two 150-kw diesel generators, two high-velocity (3000 cubic feet per minute) fans, a bilge pump, a salt-water sanitary pump, the fuel-oil transfer pumps, two winches for the personnel transfer system, and the controls for all of these. There would have to be batteries for starting the diesels, and an automatic changeover system to switch from one diesel generator to the other when power output dropped below a predetermined level. The fans could be set to run constantly, but dampers in the ventilation system could be thermostatically controlled. One ventilation system would handle only the VORTAC room, whereas the other would take care of the engine- and living-spaces. We believe that no additional heating system would be necessary since the sensible heat gain from the VORTAC equipment and diesel generators would be sufficient to keep the temperature between 65^{0} and 80^{0} all year long, at a relative humidity of less than 60%. The bilge system and the salt-water sanitary pump (for the shower and toilet) would be turned on manually when personnel

came aboard. The fuel system would include two settling tanks (to settle water from the fuel oil) that would also serve as day tanks. The level in these tanks would be monitored by float switches, and they would be supplied from a manifold on the suction side of the fuel-oil transfer pump so as to draw equally from each of the four double-bottom tanks.

Fresh water for the buoy could probably be supplied by the Coast Guard cutter since only a small amount would be required. This water could be transferred to the buoy by means of a relatively light hose and stored in a tank over the storage compartment and adjacent to the living space, or over the living space itself. Gravity would allow the water to be used for galley or washing purposes. It is also possible that fuel oil might be supplied similarly. Each Coast Guard vessel could, just before going off station, transfer to the buoy whatever quantity of fuel oil it could conveniently spare. Otherwise, fuel oil would have to be supplied by a regular tanker at least once a year. These, and other details, would have to be worked out completely in a final design, but should not be difficult.

One of the problems given consideration, particularly with respect to the unmanned buoy, concerns the means by which technicians aboard the Coast Guard cutter could be transferred to the buoy periodically for routine maintenance, and at other times when VORTAC equipment or other equipment on the buoy were not functioning properly. Talks with the Coast Guard have indicated they would probably transfer men by small boat in preference to any other method, if the sea and wind conditions were not too severe. We believe, however, that there may well be extended periods of several weeks in the winter when small-boat operation would be exceedingly hazardous and certainly very uncomfortable. Although the crew of the cutter might be well trained in launching a small boat from the cutter, and in retrieving it, the transfer from the small boat to the buoy would be another matter. An unmanned buoy would have no one to take a painter from the boat or assist the technicians coming aboard in any way. Furthermore, the technicians would probably get drenched as they climbed up the ladder on the outside shell of the buoy, or any of the unmanned platforms, and there would be constant danger of slipping, either from the ladder or on the weather deck. There seems little doubt that this method of transfer would be unsatisfactory on many occasions, and entirely out of the question much too often.

The scheme suggested by the writers may also leave much to be desired with respect to the absolute safety and comfort of the technicians being transferred, but does offer less danger in bad weather than the small-boat transfer. Basically the method proposed is similar to the high-line transfers now used by the Coast Guard and the U. S. Navy. The primary differences are that men are not used to maintain tension in the high-line, and that instead of a trolley-

supported breeches buoy or other carrier traveling along the high-line, the carrier is fixed into the line itself so as to travel with the line. The system can best be understood by means of the sketches shown in Figure 8 and the following description of how it might be operated.

Extending essentially downwind from the buoy at all times, two flotation lines would serve to permit the Coast Guard cutter to make contact with the buoy. The ends of both these lines would be shackled to either end of a small, light spar which could be picked up from the deck of the cutter by means of a ring, with a reeving hook. The spar would normally be some three hundred feet from the buoy. If no appreciable sea or wind were present, the spar would be closer to the buoy and perhaps even somewhat entangled in it. This would be temporary, however, and eventually the wind would probably cause the spar to stream downwind again and disentangle the two lines. During calm periods we believe that the cutter could, without danger, approach the buoy quite closely and manage to obtain the lines directly or still pick up the spar.

One of the two lines would be connected to the buoy at the lower outside edge, halfway between the two sails, or at what is assumed to be the farthest downwind location on the periphery of the buoy. This line would be made secure to the port bitts on the forward deck of the cutter after being led through the appropriate chock or fairlead for these bitts. The cutter would presumably have taken a range from the buoy consistent with the captain's judgment on the desired proximity. Probably this distance could be one hundred feet, or even closer, on most occasions. It could be greater (up to nearly the full three hundred feet of line available) if the length and height of the waves made this more desirable. The cutter would then stream downwind from the buoy, the buoy itself performing in all respects like the usual mooring buoy. Needless to say, the whole operation would not be attempted in extremely bad weather, when high wind and wave forces on the cutter could put too great a strain on the mooring, or when it might be too dangerous even to have men working on the forward deck of the cutter.

The other of the two lines taken aboard the cutter with the spar would be connected to the top of a carriage near the top of the tower of the buoy. This line could be led through a snatch block attached to the upper edge of the side of the gun turret on the cutter, the turret having been rotated so as to have this side perpendicular to the straight line from the tower to a point on the center-line of the cutter as far back from the bow as the turret. This line would then be led through a second snatch block attached further down the side of the turret, and then to one of the gypsies on the windlass. Taking in on this line would override the tension provided by two winches aboard the buoy to two lines from the other side of the carriage top which lead over pulleys at the top of the tower and down through the tower to the winches. These winches would be hydraulically controlled (estimates of the cost of this type of control system have shown it to be preferable in performance and cost) to hold a constant tension (perhaps 4000 pounds) and

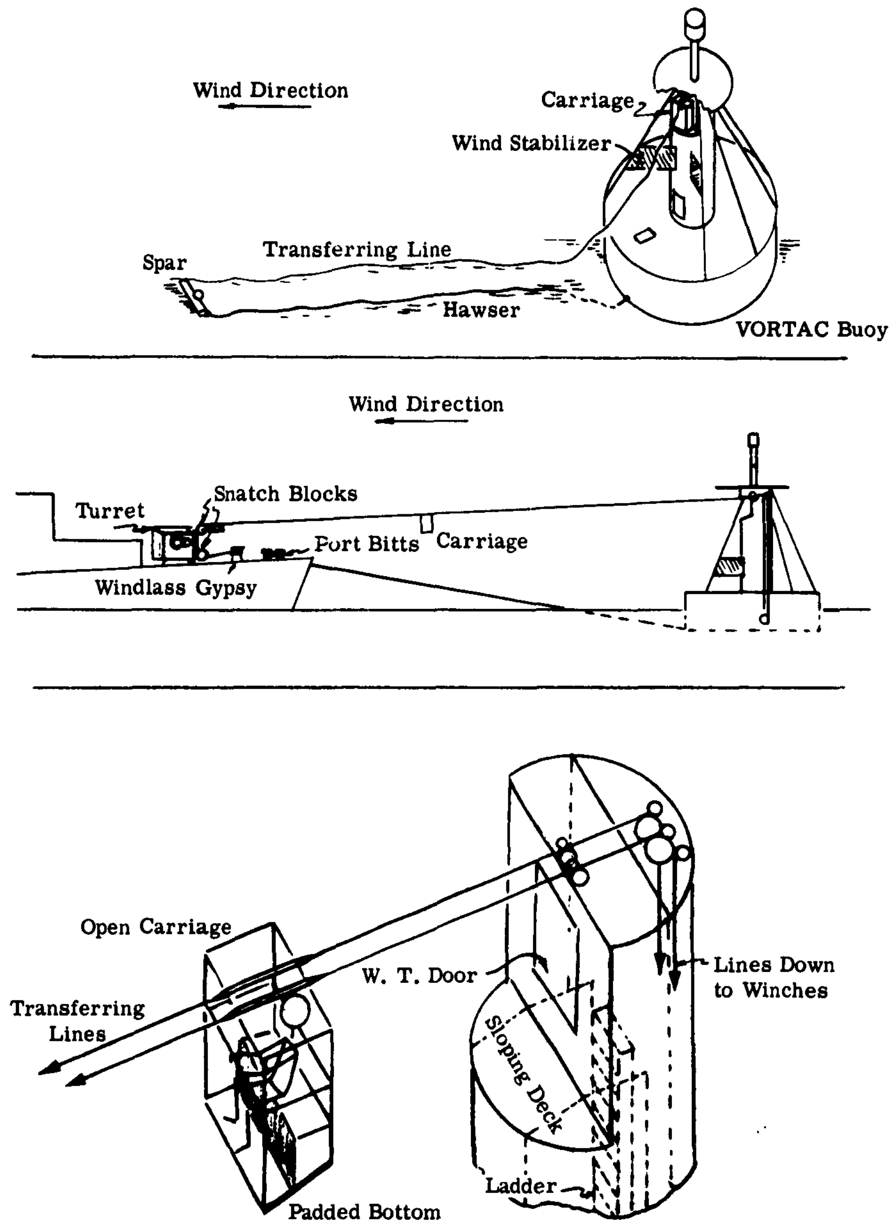


FIGURE 8. PROPOSED TRANSFER SCHEME

would automatically reel in rapidly when this tension was not opposed. The effect of the winches would be that of large weights hung on each of the lines: sufficient force exerted by the windlass gypsy would reel the line and carriage toward the cutter while the weights would rise or fall as the ship or buoy rolled or surged, without the tension becoming sufficiently large to break one of the lines.

When the carriage were all the way to the cutter, it would actually compress a coiled spring fitted to the upper snatch block, but would be positively held by the line to the gypsy. At this time a second line, coiled up inside the carriage and connected to the top of it in the same manner as the flotation line used to reel the carriage to the ship, would be led through two similar snatch blocks mounted beside the others on the turret and to the other windlass gypsy. The first technician would get into the carriage and be sent to the buoy as the first line was paid out over the gypsy. The second line could also be kept reasonably taut, and is intended to serve as a safety feature in case the other line were to part. For that matter, two entirely different lines kept aboard the cutter could be used in returning the manned carriage to the buoy after it was initially brought to the cutter by the first flotation line, if the first line were thought to be deteriorated enough to be unsafe.

If the carriage were kept very light, it is believed that the tensions would never have to exceed 20,000 pounds even instantaneously, and that 1 1/2-inch-diameter polypropylene line could be used for the flotation line or for all the carriage lines if desired. The flotation hawser, on the other hand, would probably have to be 4-inch-diameter polypropylene. These and other details would have to be worked out, in conjunction with the Coast Guard, if the scheme were to be used. The carriage need not be shaped as shown in the figure, for example, and could actually be made watertight if it were considered necessary. On the other hand, we feel that there is greater probability the carriage might strike the prow of the cutter instead of the water if the tension system were properly designed, and therefore moving the snatch blocks to a much higher point in the cutter than shown would be a clear improvement. There is no doubt the system could require some additions or alterations to the cutters, but if the Coast Guard were convinced by experience that the scheme would work well, they would probably be interested in using it in other operations. In any case, some such scheme will evolve from studies and development work now being carried out for or by the U. S. Navy.

3.1.6. UNMANNED SEADROME. The term "seadrome" is used differently by different people, but for this report will be used to denote any large floating structure that is intended to serve as a platform at sea. We understand that the "Armstrong Seadrome" is a proprietary version of such a platform and was originally designed to be utilized as a floating "airdrome." The principal advantage of a large floating structure as it might apply to the study in question is

the possibility of placing most of the buoyant volume at some distance below the water surface so as to decrease wave forces and the platform motions they create. The concept is sound, and there is no doubt that a seadrome, given unlimited financing, would in many respects be the ideal means by which a VORTAC station could be placed at Ocean Station Charlie. A sufficiently large floating structure could be devised that would provide a very stable platform and all the space needed for the VORTAC installation in addition to a helicopter landing area, but for the purposes of this study it was not deemed necessary to rough out such a design in any great detail. Sufficient data were gathered on existing plans for such structures to allow them to be evaluated as a group with respect to initial cost (including mooring), safety, ease of maintenance, etc. As will be noted in the later section of this report wherein the various platforms considered are evaluated and discussed, the seadrome concept does not compare favorably with most of the others.

The seadrome must be large in order that its inherent advantages may be exploited. The center of buoyancy should be 100 feet or so below the water surface. The lateral dimensions should also be large, since it is customary to gain stability by distributing the volume and waterplane into vertical cylindrical elements tied together by trusses. This distribution naturally leads to large platforms. To use the same concept on a smaller scale when a much smaller platform is required is, in a sense, a misuse of the concept. None of the advantages and all of the disadvantages of the larger version would be inherent in such a design. These disadvantages could best be eliminated by radical departure from the seadrome concept and, the writers think, a design similar to the buoys described elsewhere in this report would result.

Thus the unmanned seadrome would be a large structure of the type shown in Figure 9. The VORTAC equipment arrangement, engine-room space and the machinery it would contain, and the living space and support systems would all be similar in size and number to those described for the unmanned buoy. These would probably be placed on the top platform and the deck above used for the counterpoise and to support the antennas. Technicians would be quartered aboard the Coast Guard cutter and transferred to the seadrome for maintenance and repair. Even the tower transfer system described for the unmanned buoy could be incorporated into the design. A greater supply of fuel oil could be carried aboard and other supplies could be stored in greater quantity.

Particularly significant is the possibility that a heliport could also be incorporated into the design. Although the three sizes of Coast Guard cutters now being used for Ocean Station Charlie patrols do not now carry helicopters, conceivably certain of these or new cutters would do so within a few years. Transfer of personnel and supplies by helicopter has many advantages over both the small-boat and the tower transfer system, and would be less uncertain. Because

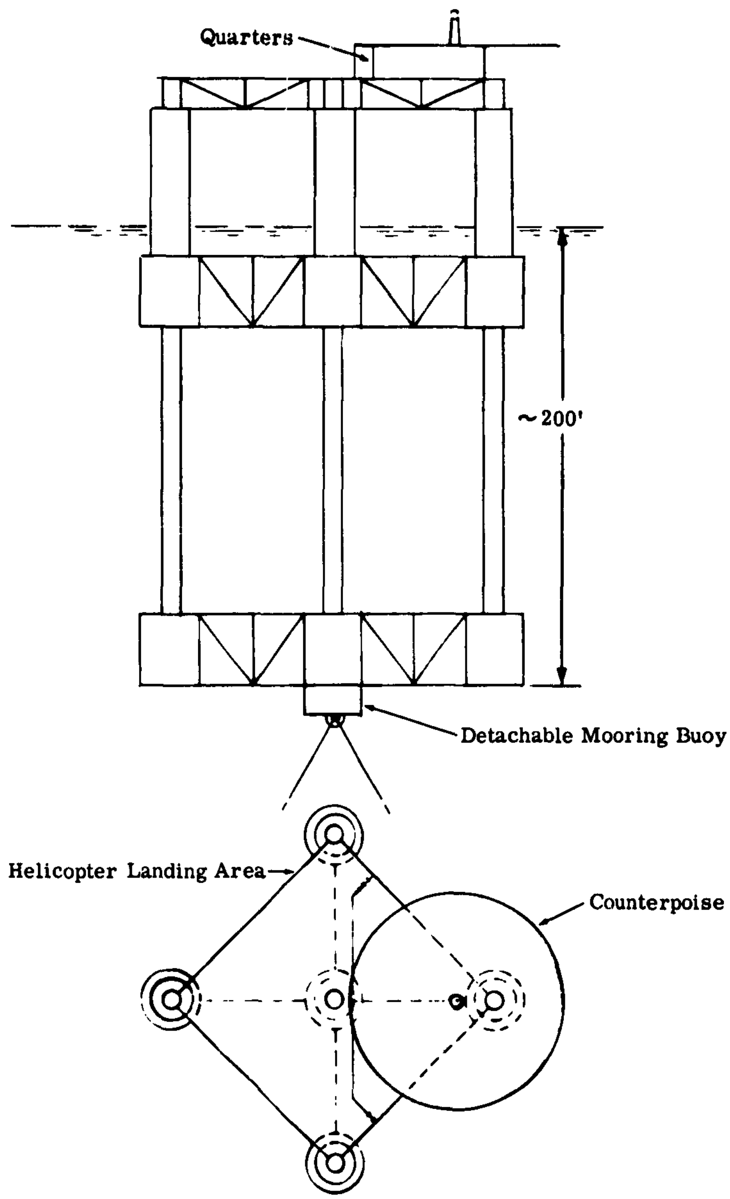


FIGURE 9. SEADROME CONCEPT

the seadrome would not have appreciable roll (and/or pitch) and does provide sufficient deck area, the use of large helicopters seems more feasible than for the moored Liberty ship.

The cost of such a platform would be relatively very high because of the engineering studies which would have to be made as a basis for its design, the difficulties in building it, and the expensive mooring it would need.

3.1.7. MANNED SEADROME. The size and configuration of the manned seadrome considered suitable for VORTAC would in most respects be very similar to the unmanned seadrome. The additional quarters and support systems required would be partially offset by the necessity of only one dual VORTAC and thus the general arrangements could be much the same. The personnel aboard would benefit from the relatively small motion amplitudes and accelerations, and presumably find their stay more pleasant than they would on either a moored or free ship or the smaller manned buoy described previously.

The machinery and accommodations needed would be very similar to those described for the Liberty ship and the manned buoy. The mooring would be the same as for the unmanned seadrome. The initial cost would also be relatively high for the same reasons.

3.1.8. SUBMARINE. Another possible platform considered is a modified World War II fleet-type submarine that might be obtained from the U. S. Navy's reserve fleet. The modifications would include adding a counterpoise on top of a modified conning tower and the removal from the hull of much of the special equipment for handling ballast, firing and storing torpedoes, providing air, etc. The diesel electric propulsion system would be left intact and made operable. A view of the platform is shown in Figure 10.

The motions of the submarine in heavy seas could be rather violent and exceedingly troublesome and uncomfortable for the personnel aboard. Extra-large bilge keels might be fitted, but there seems little point in considering the addition of more elaborate stabilizing devices. The scheme anticipated for utilizing most fully the advantages of the submarine, as compared with other possible platforms, involves mooring the ship by a single mooring chain to a floating buoy in such a manner that it could slip its mooring when the weather and sea were particularly bad. This would be done more as a means of lessening the force on the mooring than for the safety of the ship, but could be appreciably beneficial in the latter respect also. As long as the propulsion plant were available it would be worthwhile to use it.

The counterpoise and antenna installation would require careful design. The counterpoise could probably be not more than 20 feet above the waterline and would have to be kept small in diameter to maintain sufficient stability. As the freeboard at midships would probably be less

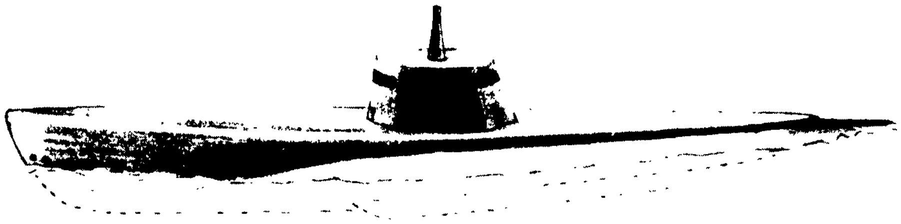


FIGURE 10. MODIFIED FLEET-TYPE SUBMARINE

than 5 feet, the waterplane area would be considerably reduced in even a relatively mild sea, and it would be necessary to keep the center of gravity below the center of buoyancy at all times.

The final arrangement of the VORTAC equipment and the living spaces could be handled in several ways. More than sufficient space is available for the anticipated crew of twelve to fifteen, and all of the support systems for the crew could be used in their present form. Some reconditioning may be required, but it is the writers' impression that the reserve ships of the U. S. Navy are in substantially better condition than Liberty ships, for example, of the same vintage.

The first cost of the modified submarine as a possible VORTAC platform is not subject to very precise analysis, but the modifications might be rather expensive because of the complexity of many of the components that would either be removed or require adaptation for their projected use. In common with the other manned platforms, the operating costs for the submarine platform would be higher than for any of the unmanned schemes.

3.1.9. DUAL ORIENTATION BUOY. Another platform worthy of consideration for mounting VORTAC at Ocean Station Charlie is a long cylindrical buoy similar in many respects to the "Flip" devised by the Marine Physical Laboratory of the Scripps Institution of Oceanography. Such a structure is in one sense a simplified version of the seadrome concept (at least as denoted in this report) or, alternately, a more elaborate version of the unmanned buoy already described. As such, it is conceivable that it could incorporate in its design many of the advantages of both platforms.

A view of what the writers feel might be a possible configuration for this special buoy is shown in Figure 11. The overall length of 250 feet is an arbitrary choice meant to indicate order of magnitude. The primary advantage of the great length is that the bulk of the bouyant volume would be sufficiently below the surface to preclude the structure's motions being violently affect-

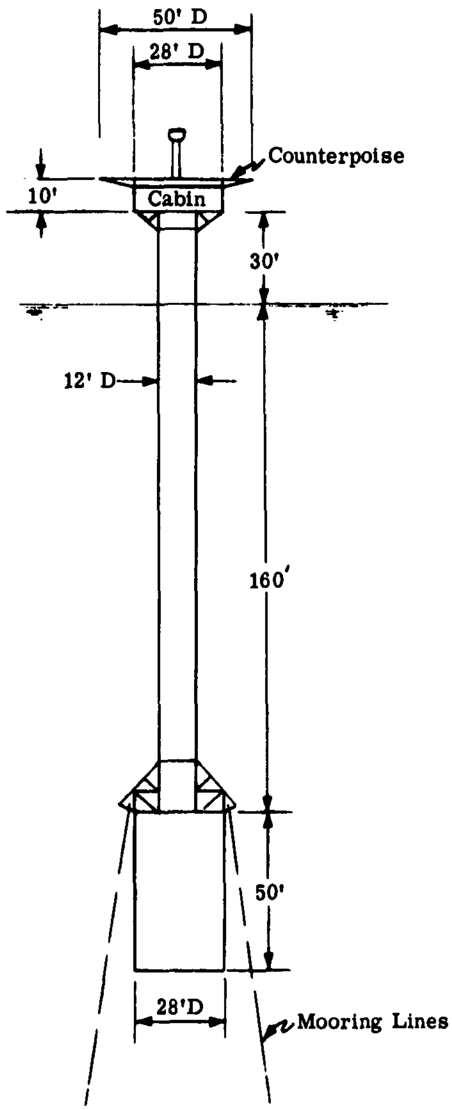


FIGURE 11. DUAL ORIENTATION BUOY CONCEPT

ed by the wave forces. The circular cross section could remain constant in area over the entire length, but this is not necessary, since the resulting volume is not required for utilization. The single deck above the waterline could well be approximately 28 feet in diameter and utilized in much the same manner as that shown for the inner space of the unmanned buoy in Figure 7(c). The lower large cylinder could also be 28 feet in diameter and 50 feet long. The structure between these two might be 12 feet in diameter (or less if reinforcing members were permitted to be placed outside the plating). The configuration described would place the center of buoyancy just above the transition section at which the mooring lines would be attached, and would permit the center of gravity to be located below this. The most desirable location of the center of gravity might be determined after the actual platform was moored, since the manner in which the ballast tanks in the bottom cylinder were flooded could allow for considerable variation in its position. The displacement of this configuration would be about 1400 long tons at the waterline shown. The 30 feet from the waterline to the cabin is perhaps excessive, but 20 feet would not be sufficient.

The fact that this buoy could be "flipped" to the vertical orientation after having been towed to Ocean Station Charlie in the horizontal position would greatly facilitate its installation. Temporarily buoyed mooring lines could be attached prior to the change in orientation, for example, and the mooring task thus would be relatively simple. The actual flipping operation could be accomplished by means of special equipment temporarily carried by the salvage tug that towed the buoy to the site, rather than by systems built into the buoy itself. The technique used would be similar to that for the Scripps "Flip," some compartments being free flooded while others used for control were flooded at the desired rate by means of special venting arrangements. The experience with "Flip" is a major factor in asserting that this dual orientation buoy is in fact feasible.

The writers feel that a ship-shape bow as used on the Scripps "Flip" would not be required for the proposed VORTAC buoy. The fact that this buoy would only be flipped twice (once when it was initially placed on station and then when it was taken out of service), and hence towed horizontally only twice, would make such a design an unnecessary expense as well as a needless complication. The extension of the counterpoise to perhaps 50 feet in diameter and the installation of the VOR and TACAN antennas would be accomplished at Ocean Station Charlie, after the buoy was flipped. The top deck could be fitted with a temporary heavy plate to be unbolted on site and replaced with a similar plate with the antennas already attached. The counterpoise extension could be mesh, supported by radial members that would fit into brackets at the deck edge.

The ballast tanks in the bottom portion of the buoy would preferably be lined with one of the available hot plastic coatings for preventing, or at least greatly reducing, corrosion. Since the buoy would be flipped by flooding with salt water, on site, and all of the tanks used would not necessarily be completely filled, this is a matter of some concern. (If it were not that the buoy would eventually have to be returned to the horizontal position and towed back, some scheme might be devised in which concrete, for example, might be used to replace the salt-water ballast used during the flipping operation.) The piping to the various ballast tanks could be run inside the 12-foot-diameter section and all connections required placed just under the cabin deck. Fuel oil would be stored in circular tanks along the 12-foot-diameter section in the vicinity of the waterline so that the pumps required to supply the fuel to the diesels would not have to be too large. An axial trunk could be continuous along the full length (height) of the buoy, but it and the volume generally would have to be subdivided at about every 20 feet by a watertight bulkhead to protect against progressive flooding of the buoy if it were damaged. It is believed sufficient reserve buoyancy would thereby be provided.

The machinery required would be almost identical to that prescribed for the smaller unmanned buoy discussed earlier in this report. The ventilation system, fresh water system, and even the tower-transfer scheme described for that buoy could be incorporated into this one with only minor modifications, since the effect of a tower is obtained with this buoy in its vertical orientation.

Two dual VORTAC systems would also be included in this buoy. No thought was given to having this buoy manned, since the motions would either be small in amplitude with large acceleration and hence be uncomfortable, or else the amplitudes would be larger than desirable for the comfort of a regular crew. A manned structure of this general type would preferably be a large seadrome similar to that already described. The personnel required, and their functions, would therefore also be similar to those for the smaller unmanned buoy, and they would be quartered aboard the Coast Guard cutter at Ocean Station Charlie and replaced when it was relieved.

3.2. ELECTRONIC EQUIPMENT AND ANTENNAS

The supporting studies of navigation systems have been primarily aimed at determining the best TACAN and VOR systems presently available for application aboard a sea platform. In the course of the investigations, several problems have been encountered with respect to adapting existing systems to one or more of the proposed mounts. Each problem has been examined and a solution has been suggested based on current technology.

3.2.1. ELECTRONIC SYSTEM EQUIPMENT. The determination of applicable hardware is guided by equipment weight and size, power requirements, and maintenance requirements and reliability. The various parameters are interrelated to a great extent, but reliability appears to be the limiting factor in equipment currently available.

3.2.1.1. VOR Systems. Investigation revealed that all present VOR beacons are substantially in the same state of technical development. The Wilcox VHF OMNIRANGE series 483 (Dual System 97217) was selected as representative in determining the physical characteristics of the hardware. That choice was made purely on the basis of information available.

No particular electronic design is recommended except that a dual system with a monitoring and switching unit would be highly desirable for the sea application, which would require continuous service.

3.2.1.1.1. Physical Characteristics and Power Requirements. The gross physical characteristics of the hardware and power requirements are shown in Table II for a dual beacon system. The equipment is tube-type and is compacted in chassis and cabinets, in the manner of most commercial electronic equipment.

TABLE II. DESCRIPTIVE INFORMATION: DUAL VOR SYSTEM

(a) Hardware:	
4 cabinets	74 × 24 × 17 inches
1 cabinet	10.6 × 22 × 14.75 inches
TOTAL WEIGHT	approximately 2300 lb
(b) Power Requirements:	
Source:	2- or 3-wire, single-phase, grounded or ungrounded neutral, 50-60 cps, stabilized within the range of 190-260 watts (40 amp max)
Consumption:	approximately 10 kw
(c) Operation:	Output: 200 watts Frequency Range: 108-118 Mc

3.2.1.1.2. Reliability. Present VOR equipment seems to be very reliable when adequately maintained. The FAA Airway Facility Performance Reports for the first six months of 1961 show that the FAA operated VOR's were in operation for an average of more than 98% of total available operating time. At least one dual VOR station has been reported to operate an entire year without failure.

Records of continuous unmanned operation without routine maintenance, as would be required in an unmanned sea platform, are not available. A rough figure for the mean time between failures (MTBF) was computed for the Wilcox VOR and found to be 700 hours for a single beacon. The reliability for a dual system, assuming the monitoring and switching functions to be perfect, can be computed as follows:

$$R(t) = \left(1 + \frac{t}{MTBF}\right) e^{-\frac{t}{MTBF}}$$

Substituting,

$$R(30\ \text{days}) = \left(1 + \frac{720\ \text{hr}}{700\ \text{hr}}\right) e^{-\frac{720\ \text{hr}}{700\ \text{hr}}} = 0.728$$

Similarly, R(14 days) = 0.92. Thus even with the favorable assumptions of perfect monitoring and switching, if the equipment is serviced at monthly intervals, down time can be expected for some period three out of each ten months, or, if bi-weekly maintenance is provided, once out of each ten 2-week periods (roughly twice each ten months). Sea conditions in the North Atlantic are such that service could not be guaranteed on any set schedule, however. The upshot is that one dual VOR system is probably not reliable enough for unmanned sea operation.

There are several methods of improving the reliability of the equipment. The crudest method is to use complete redundant systems—in this case, redundant dual units. For example, if the same optimistic assumptions are made as before, the reliability of two dual VOR units would be 97^{+}% for four weeks continuous operation and 99^{+}% for two weeks. Reliability of this degree might be satisfactory.

Some other techniques for improving reliability are: using redundant components in the system, replacing tube-type components with solid state components and increasing heat-dissipation capabilities. It is conceivable that one might produce a single VOR with the desired reliability by using such techniques.

3.2.1.1.3. Application to Sea Platforms. The present VOR dual systems can be adapted to any platform that will permit routine maintenance. One dual system on any manned platform should provide essentially 100% reliability. The equipment should be installed with shock mountings to damp out shocks and vibrations, and if possible, the equipment room should have controlled low humidity. The present hardware configuration could be re-modulized to fit conveniently in any particular electronic room as required.

As discussed earlier, two dual systems might provide acceptable performance for an unmanned platform. It would be necessary to provide a switching circuit between the dual systems. The comments on modification of a single dual system to a sea platform are applicable.

3.2.1.2. TACAN Systems. Current TACAN systems are more diverse in technical development than VOR. Three general systems have been considered for application to a sea platform:

(a) The newly developed TACAN-for-VORTAC installations.

(b) Systems such as the AN/SRN-6 (shipboard counter part to AN/GRN-9) that is currently in use.

(c) The TRN-17, which represents a developing line of miniature systems.

3.2.1.2.1. Physical Characteristics and Power Requirements. Gross physical characteristics of the hardware, power requirements, and salient operating features of the various systems are set forth in Tables III through VI.

TABLE III. DESCRIPTIVE INFORMATION: TACAN-FOR-VORTAC (DUAL BEACON AND MONITOR)

(a) Hardware:	
4 cabinets	83 × 30 × 33 inches
2 cabinets	76 × 30 × 27 3/4 inches
1 cabinet	101 × 30 × 27 3/4 inches
2 cabinets	76 1/32 × 30 × 27 3/4 inches
TOTAL WEIGHT	Approximately 10,000 lb
(b) Power Requirements:	
Source:	60 cps, 3-phase, 4-wire, 208 or 240 volts
Consumption:	Approximately 35 kw
(c) Operation:	Peak Output: 23.5 kw Frequency: 962-1213 Mc

TABLE IV. DESCRIPTIVE INFORMATION: AN/SRN-6 TACAN (TWO BEACONS)

(a) Hardware:	
4 cabinets	25 × 34 1/8 × 72 inches
1 cabinet	27 1/4 × 11 13/16 × 49 inches
1 cabinet	38 1/4 × 15 1/2 × 56 1/2 inches
2 cabinets	10 7/8 × 11 1/16 × 14 3/8 inches
TOTAL WEIGHT	Approximately 5500 lb
(b) Power Requirements:	
Source:	60 cps, 3-phase, 440 volts
Consumption:	Approximately 26 kva
(c) Operation:	
Peak Output:	7.5 kw
Frequency Range:	108-118 Mc

TABLE V. DESCRIPTIVE INFORMATION: RTC1
TEST-MONITOR CONTROL UNIT

(a) Hardware:	
2 cabinets	76 1/32 × 27 3/4 × 22 inches
2 cabinets	76 1/32 × 27 3/4 × 22 inches
1 cabinet	26 1/2 × 24 1/2 × 20 1/2 inches
4 cabinets	7 7/8 × 29 1/4 × 9 1/8 inches
TOTAL WEIGHT	Approximately 2500 lb
(b) Power Requirements:	
Source:	60 cps, single-phase 208 volts fed from 208-volt 3-phase source or 240 volt single-phase source
Consumption:	Approximately 6.5 kva

TABLE VI. DESCRIPTIVE INFORMATION: TRN-17
SYSTEM

(a) Hardware:	
2 cabinets	24 × 24 × 71 inches
1 cabinet	24 × 40 × 71 inches
(b) Power Requirements:	
Source:	60 cps, single-phase, 120 or 240 volts
Consumption:	Approximately 9 kw (including about 6 kw for heaters and ventilators)
(c) Operation:	
Peak Output:	1^+ kw (augmentable to 3^+ kw by removing 60-db filters)
Frequency Range:	962-1213 Mc

(a) The TACAN-for-VORTAC is an extremely large and sophisticated system. It was developed to overcome difficult land-installation siting situations (such as hangars) that are not present at sea. These considerations make TACAN-for-VORTAC inappropriate for the intended sea application.

(b) The AN/SRN-6 was designed for use aboard Navy vessels, and has been used extensively by the Navy as a single-beacon system. This system is tube-type and complex; consequently, frequent skilled maintenance is required. It would be desirable to have a dual system with

automatic switching for VORTAC application, which demands continuous operation. The Test, Monitor and Control (TMC) unit now in use monitors many of the parameters of the TACAN output and switches units when there is a failure. The TMC is a dual system within itself and provides multiple operating combinations of either of the two beacons with either of the two monitors. The TMC is large and complex in its own right and probably requires more careful maintenance than the beacons.

(c) The TRN-17 represents the development of a new class of TACAN systems. It is a dual-beacon, single-monitor system designed for the Air Force as a trailer-mounted tactical unit. The TRN-17 is a tube system but is much less complex than the others (for example, the monitor has 46 tubes as compared to over 500 in the TACAN-for-VORTAC monitor). The system is compact, rugged and versatile. It can be operated as a rho-theta NAV-AID or it can be operated as a DME only.

The U. S. Navy Weapons System Test Division, Patuxent River, Maryland, made a technical evaluation of the TRN-17 in June 1962. Although the peak output of the system is relatively low 1^+ kw, all flight tests were rated satisfactory to excellent. TACAN lock-on was obtained at ranges up to 200 miles at 40,000 feet. The system could provide a 3-kw peak output by removing the filter-cavities that suppress the output signal 60 db 0.8 Mc away from the center of the 0.5-Mc operating band. Filtering might not be required at sea because the likelihood of interference is small.

The TRN-17 proved its physical endurance in passing the Munson Road Course, the Cross-Country Test and Railroad-Humping Test at Aberdeen without failure, and presently it is undergoing environmental tests at the International Telephone and Telegraph Federal Laboratories.

The Air Force is developing a solid-state, dual-monitor version of the TRN-17 that should be ready for tests in about a year. This system should be more compact and reliable than the tube version. The Navy also plans to develop a solid-state system to replace the AN/SRN-6. That system is expected to be designed for about 7.5-kw peak output.

3.2.1.2.2. Reliability. The maintenance requirements for the TACAN-for-VORTAC and AN/SRN-6 have already been mentioned. No operating records for the TACAN-for-VORTAC are currently available. The FAA Airway Facility Performance Tests (January through June 1961) show that the FAA AN/GRN-9 TACAN's were in operation for an average of over 97% of total available operating time. This record indicates that the AN/GRN-9-type system can produce reliable operation when adequately serviced.

The specifications of the TRN-17 require an MTBF of 336 hours for each beacon, and continuous unattended operation for 168 hours for the system. Reliability calculations made with

the specified MTBF indicate that the reliability figure for continuous operation without maintenance for 30 days is poor (37%). Redundant dual systems (assuming perfect monitoring and switching) provide only 83% reliability for the desired 30-day operation, if the specified 336 hour MTBF is correct. The evaluation tests at Patuxent River indicate that this figure might be pessimistic. During the tests the system operated continuously with no maintenance for 542.5 hours (22.6 days) before being cut off intentionally. There were no failures in either beacon and only two minor failures (one indicator lamp and one relay contact) in the system. A breadboard TRN-17 monitor operated 1400 hours continuously without maintenance or failure. One test is not conclusive, but extrapolation of the results indicates the possibility that two dual TRN-17 systems in redundant, standby operation might prove reliable enough for the intended application.

Further, the solid-state system can be expected to be more reliable than the tube version.

3.2.1.2.3. Application to Platform. AN/SRN-6 beacons could be used aboard any manned platform in the present configuration, but the TMC unit should be ruggedized and shock-mounted according to the circumstances.

The TRN-17 system may be the best presently available for any platform from the standpoint of reliability, and space and power requirements. This system may also prove to be sufficiently reliable in a two dual-system, redundant, standby configuration for use aboard an unmanned platform.

3.2.2. ANTENNAS. A seaborne application of VORTAC introduces several considerations not pertinent in a ground installation. Most significant of these are azimuth error introduced by roll and pitch of the platform and problems in mounting the VOR and TACAN antennas substantially enough to withstand the rigors of the sea environment and so as to prevent mutual interference in the radiated signals.

3.2.2.1. Platform Motion. The effect of ship's motion was evaluated during the FAA Task No. 115-04-02T, "Test and Evaluation of Oceanic Station VORTAC." The performance of VORTAC on that test was favorable notwithstanding ship's roll up to 30°. A slot-type, unstabilized, VOR antenna on a 15-foot counterpoise and a modified SRN6-1801, 20°-roll-stabilized TACAN antenna were installed on USCGC Androscoggin for the tests. VOR was placed on the foremast and TACAN on the mainmast.

The VOR azimuth was found to be more affected by motion than TACAN, particularly in nulls of the radiated pattern caused by interaction of the direct and reflected signals. It has been suggested that this effect can be lessened by designing the counterpoise to tilt up the radiated pattern and by stabilizing the antenna, and/or by building a vertically polarized antenna.

The increased vertical directivity would decrease the amount of energy reflected from the ocean surface, of course. Vertical polarization also decreases reflection because the reflection coefficient of sea water for vertical polarization is substantially less than for horizontal.

Because TACAN is vertically polarized, the nulls in its radiated pattern are not as deep as for VOR, but the higher frequency TACAN (1000 Mc) produces a pattern with more and sharper lobes than VOR (100 Mc). It is, therefore, necessary to stabilize the TACAN antenna to prevent oscillation of the sharp lobe structure which would result in roughness and azimuth variation in airborne receivers. Engineers of the ITT Federal Laboratories have indicated that this effect probably is not severe if roll is less than 10 or 12°.

3.2.2.2. VOR Antennas. The choice of VOR antenna is between the FAA four-loop and the Alford slot-type. The slot-type has the advantages of compactness and relative ease of weather-proofing. One of this type of antenna was used in the *Androscoggin* tests and seems more appropriate for most sea applications. The four-loop is used extensively in ground VORTAC installations, but requires a large radome to cover the entire assembly and is less desirable at sea.

The Lorentz VOR antenna, used extensively in Europe, was examined briefly and found to be inapplicable because of its large size and because it has an exposed rotating dipole to produce the time-varying signal instead of electrical rotation.

3.2.2.3. TACAN Antennas. Several TACAN antennas have been designed explicitly for shipboard use. Table VII depicts the prominent characteristics of those available. The URN-3, SRN-6, and TACAN-for-VORTAC antennas are less applicable than the TRN-17 and SRN 6-1801 because of their large size and weight.

As previously mentioned, any sea platform that rolls more than 10 or 12° will require a roll-stabilized antenna. Thus the SRN 6-1801, in the configuration utilized aboard the USCGC *Androscoggin*, is appropriate for all applications considered except the manned and unmanned buoys. One modification is necessary, however. The SRN 6-1801 is a Navy highband antenna (see note, Table VII) and current FAA installations are lowband. To convert the SRN 6-1801 to highband operation would require some modification. The antenna used on the *Androscoggin* was modified for one-channel, highband performance. Should the FAA decide to use lowband at sea, the present model would be satisfactory.

The circular manned or unmanned buoys have an added dimension for TACAN stablization. Because buoys are round, there will be no set roll axis, and for rolls over 10 or 12°, a plane-stabilized TACAN antenna would be necessary. The URN-3 and SRN-6 are 20°-roll-stabilized and 7°-pitch-stabilized, but do not meet the requirements for plane stabilization. In the event

TABLE VII. TACAN ANTENNAS

1. URN-3 - Approximately 1000 pounds, 4-inch diameter, 7 or 8 feet high
   Roll-stabilized 20°; pitch-stabilized 7°
   Azimuth stabilized to ship's gyro
2. SRN-6 - Approximately 700 pounds, 4^{+}-inch diameter, 5 or 6 feet high
   Stabilization same as URN-3
3. SRN 6-1801
   Approximately 350-400 pounds, 3-inch diameter, 3 feet high
   Roll-stabilized 20°
   Azimuth-stabilized
   Lowband
4. SRN 6-1801 types without any stabilization
5. VORTAC installation - Approximately 700 pounds, approximately the size of the URN-3
   No stabilization
   Highband
6. TRN-17 - Approximately 200 pounds, 3-inch diameter, 3 feet high
   No stabilization
   Allband

Note: Lowband: 962-1024 Mc transmitter; 1025-1087 Mc receiving
Highband: 1151-1213 Mc transmitter; 1088-1150 Mc receiving
The Navy uses lowband. FAA ground stations use highband.

the buoys require stabilization, a modified plane-stabilized version of the SRN 6-1801 seems appropriate.

If the buoys are as stable as expected, a TRN-17 or unstabilized, SRN 6-1801-type antenna could be used. Either would require modification for azimuth stabilization; that is, to provide variable heading reference as the ship's heading changes. The TRN-17 is smaller and lighter than SRN 6-1801-types and it is allband (high and low), and, accordingly, would not require modification to highband. The SRN 6-1801 types have better vertical directivity, however, which might result in less objectionable null patterns.

Several antennas have been proposed to alleviate the stabilization problem, but the Navy seems satisfied with the SRN 6-1801 at present.

3.2.2.4. Antenna Mounting. The placement of VOR and TACAN antennas on a sea platform introduces interacting siting and structural difficulties. Ideally, the antennas should be co-located, as in a land VORTAC station, to minimize mutual interference. Co-location may not be possible in all platforms with present equipment.

Antennas on a vessel are, in general, subject to more severe wind loads than those on land and, in addition, to significant dynamic forces from accelerations caused by roll and pitch of the platform, vibrations from the hull, and possible wave action. The antenna system in most VORTAC installations consists of a four-loop VOR antenna, a TACAN antenna and a 16-foot, plastic radome. The radome protects the VOR antenna from the weather and provides structural support for the TACAN antenna. This structure is completely inadequate on any sea platform that may occasionally take waves over the top.

A system similar to the VORTAC land installation might be feasible aboard a vessel that would not take water, such as the cut Liberty and unmanned buoy with superstructure. It is suggested that a newer, lighter TACAN antenna be used and lowered as near to the VOR antenna as possible without causing interference. The radome would be proportionally shorter, and smaller in diameter, and could be fabricated with ribs to increase the rigidity. Either the VOR four-loop or slot-type antenna could be used under the radome. Available antennas could be used in this arrangement, but some experimentation would be desirable to determine how much the TACAN antenna can be lowered from the present height of 16 feet.

The most feasible antenna arrangement on a platform such as a trawler or Liberty ship would be to mount the TACAN antenna and VOR antenna on separate masts, as on the Androscoggin. Present equipment could be utilized.

The manned buoy or submarine present the most difficult problems because they would probably be too small to allow mounting the antennas on separate masts without interference, and would have so little freeboard that a radome-supported TACAN antenna might be washed away in heavy weather.

Two solutions are suggested. The first is to incorporate a slot-type VOR antenna within a mast strong enough to support the TACAN antenna under the most severe conditions. The slot-type antenna is 14 inches in diameter, and calculations show that such a mast would be adequate. A representative of the Alford Company, which developed the slot-type antenna, has indicated such a system might be possible with considerable development. If the system were developed, it would be practical on any sea platform and possibly on land installations as well.

The second suggestion is to separate the loops of the four-loop VOR antenna far enough to accommodate a mast (about 12 inches in diameter) to support the TACAN antenna. A semi-spherical, non-load-carrying randome, strong enough to withstand an occasional water load, could be fabricated to protect the VOR antenna. The present four-loop antenna has an opening of about 8 inches in the center of the loops. It seems questionable that the system would retain the necessary coupling between loops if it were reconfigured to accept a 12-inch mast. This might require an extensive development program.

3.2.2.5. Heading Reference. The problem of providing a heading reference for the VORTAC equipment was considered briefly during this project. The Navy uses the ship's gyrocompass for TACAN reference, and the FAA devised a gyrocompass reference system for both VOR and TACAN for the Androscoggin tests. It is feasible that a similar system could be used on any manned platform on which the gyrocompass can be adequately maintained.

The utility of a gyrocompass on an unmanned platform in conditions of uncertain maintenance is questionable. This is especially true in an environment of frequent and rather sharp accelerations that could be expected on a relatively small buoy in the North Atlantic.

A magnetic compass reference is desirable on the unmanned platforms and possibly on all the moored platforms. The advantages are inherently high reliability and direct reference to magnetic north. The biggest drawback is magnetic deviation induced by the metal in the platform. It is expected that deviation can be compensated for to within a degree or two by current techniques. Location of the magnetic azimuth detector in the center of the round buoys should make compensation easier.

The improved magnesyn system that the Navy is developing should be suitable to sense the heading from a magnetic compass and provide an electrical reference to the VORTAC equipment.

3.3. REGULATORY REQUIREMENTS.

The regulatory requirements that must be met would differ considerably for those platforms which were moored and the modified trawler or special ship designed for the task at hand. It is perhaps an oversimplification, but for all practical purposes, the moored platforms could be of almost any conceivable size or shape and essentially exempt from any regulations other than the requirements of the Commandant of the U. S. Coast Guard in his capacity as the commander of all subordinate Coast Guard officers who would in some measure be involved in tending the platform. It would certainly be within his discretion to require that plans for the selected platform and its mooring be adjudged safe and satisfactory in materials and design by his Merchant Marine technical staff. Standards for machinery and electrical items, navigation lights, fire detection and protection systems, life boats, etc. would have to meet those indicated in Chapter I, Title 46 (Shipping) of the Code of Federal Regulations (46 CFR). There would be no disadvantage and much to gain from inspection of the finished platform by the regular Coast Guard personnel engaged in this work, and whether a certificate of inspection were actually required or given should have no bearing on this. It is true that for the unmanned platforms certain items regarding fire detection and the quality of life-saving equipment, for example, become meaningless (although even the small unmanned buoy would have at least one inflatable life raft aboard), and good engineering practice would, under the circumstances, probably require higher

standards for all machinery and electrical items than any codes. But for the manned platforms, the safety and health of the men aboard would be of great importance and any steps necessary should be taken to assure that they are effected.

A regular ship, keeping station at Ocean Station Charlie (and traveling thereto and back to base), would come under the same regulations as any similar vessel, as it at least should have done before it was purchased and modified and would have to do if it were to be resold later. While the ship was owned and operated by a branch of the government, it presumably could be exempt from having a load line assigned by the Coast Guard, the F.C.C. communications regulations, the U. S. Public Health Service standards for ventilation, ratproofing, water systems, etc., and classification by the American Bureau of Shipping. However, if the modification to the trawler, for example, seemed to affect, to some adverse degree, the structural integrity of the vessel so that it might not later be able to regain its ABS classification when out of government service, the classification society should be consulted and their advice sought as to how the change might better be carried out to meet their standards. Certainly the Public Health Service requirements should be met whether the ship were exempt or not, and much the same may be said of all the Coast Guard regular codes. Therefore, the whole question of regulatory requirements seems to the writers to be one that can best be resolved by having the appropriate people do whatever design or construction are required, whether for one of the moored platforms or for an altered, moored,or self-propelled vessel. Ship design offices and shipyard personnel would naturally handle each detail in accordance with standard practice which would satisfy all regulatory requirements, and the frequent presence at their establishments of both Coast Guard and ABS inspectors would allow any particularly difficult decisions to be considered by experienced regulatory representatives. There seems good reason to believe that any of the normal regulatory agencies, and for that matter, the U. S. Navy and Maritime Administration, would be willing to render whatever assistance they might be asked for in this regard. The U. S. Hydrographic Office of the U. S. Navy would, in fact, have to be informed of the platform in that they are the assigning authority for the International Light List.

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4
MOORING PROBLEMS

Because certain of the platforms described in Section 3 of this report can be grouped together when consideration is given to the problems involved in mooring them, it seemed to the writers most expeditious to treat these problems in a separate section. The Liberty ship and the manned and unmanned seadromes present the most difficult mooring task because of their size. The cut Liberty and the manned and unmanned buoys should be easier to moor, and the submarine mooring probably could be handled easiest of all. But all of the moored platforms require the undertaking of a venture of considerable magnitude and uncertainty. To our knowledge, there has not been a successful permanent moor set in the North Atlantic for even a very small navigation or oceanographic research-type buoy, and the experts in this field are extremely pessimistic about the feasibility of this being done now for any much larger structure. Therefore much of what follows is speculative and would be subject to revision as experience is gained in an actual similar application, or from an experimental model study that most definitely should be carried out prior to any full-scale installation.

One of the major considerations in setting a deep water permanent mooring must be the cost. Given unlimited funds, the time and talent of experienced engineers, the opportunity to conduct large-scale testing of ideas and configurations, and the help of experienced seamen, we feel that a permanent mooring could be set anywhere. Practical experience and the data from various measurements made on the full-scale versions could in time lead to reasonably economical and otherwise sophisticated techniques and practices. At the present time, however, one must make use of what is known of the art of mooring and, to an unreasonably great degree, ignore the scientific approach. Completely theoretical analyses made by the writers and others simply cannot cover the range, and in many respects do not agree with the observed behavior of moored structures.

Two developments have given considerable impetus to the belief that deep water moorings can now be successfully set, however. The first of these in the advent of synthetic line—nylon, dacron, polyethylene, and polypropylene. Their chief advantage is their much greater strength-

to-weight ratio as compared to wire cable, a superiority which renders the weight of the line itself of little consequence in the load it must carry. It has always been possible to handle this problem by attaching to the wire mooring cable at various points along its length some sort of buoyant tank, but this becomes unreasonable at great depths because the weight of the tank itself must be supported. Another solution is to support the catenary of the wire cable at one or several points along its length by a vertical wire to a buoy on the surface. This is more reasonable, but means that at least three buoys are on the surface in a three-leg mooring (prone to damage and sinking) and that the moor would be quite expensive to lay. Thus neither solution seemed feasible for this study, and both are in fact unnecessary. For all of the platforms considered it seemed feasible to limit the mooring considerations to synthetic line.

The other development, which is actually still underway, is the use of imbedment anchors. These are anchors which consist of a dart-like anchor body which is explosively fired into the ocean bottom on impact of an assembly dropped to the bottom by the mooring line. The penetration is a function of the type of bottom involved, but the holding power is reported to be reasonably consistent for different types of bottom because of the variation of penetration and the attachment scheme, which forces the imbedded body to rotate on the first pull. There does seem to be a very good possibility that these anchors, with a rated static-holding power of 300,000 pounds, will be available soon and thus could be used for mooring any of the platforms. How well these anchors may work at depths of seven or eight thousand feet is not known. The extent and cost of possible alteration of the assembly, to assure functioning at these depths, are not known. Despite this uncertainty, these anchors would be ideal for the moorings being considered and will be specified. Their cost (even with possible alterations) and the ease of setting the anchors, compared to more conventional ones, seem to the writers to justify this.

4.1. SMALLER PLATFORMS

The cut Liberty ship and the manned and unmanned buoys could be moored by three lines from the imbedment anchors to their bottom shells. The dual orientation buoy could have the three lines attached at the lower transition section (Figure 11). The lines could be 3 1/2-inch-diameter (11-inch circumference), heavy, marine lay nylon, which weighs a little over 3 pounds per foot in air. The rated tensile strength is 300,000 pounds, and the cost per pound would be about $1.75. All of these values are nominal in the sense that each needs a good deal of explanation to be understood fully. Nylon, particularly in the synthetic lines, is subject to considerable elongation, of which a certain amount is permanent. It is felt that as much of the permanent elongation as seems reasonable should be taken out of the line by pretensioning it prior to actually making up the lines to be used. This would decrease the weight per foot. On the other

hand, the full length of line needed could not be obtained in one length and three to four splices would be required. This would increase the average weight per foot. The rated tensile strength is obtained for the line as it is manufactured and depends on the length of test specimen used, the rate at which the load was applied, and other factors. Thus it too is really only an approximate value in terms of the eventual application. The price is basic, but the cost of pretensioning and splicing would have to be added.

For the purposes of the report, it has been assumed that these platforms will be moored in 7,200 feet of water. This is not necessarily a correct figure because the location of the platform in reference to Ocean Station Charlie is a problem worthy of some additional consideration. Were the buoy precisely at latitude 52°45'N and longitude 35°30'N, the depth of water would be greater. Reasonably nearby, however, are shallower areas 5,000 feet deep. It is assumed that the Coast Guard cutter on station could service the manned platform even if it were some twenty or thirty nautical miles from the cutter's normal position. The unmanned platforms should be closer, but probably still some slight distance away. In any case, it would be necessary to have the anchors placed so that the mooring lines tended to keep the lateral movement of the platforms, with different sea and wind directions, down to a few hundred yards. To assure this were accomplished, lines of no more than about 8,400 feet would be required, or a total of nearly 25,000 feet.

The three lines would at their upper end have a thimbled eye splice and be shackled to perhaps 30 or 40 feet of 2-inch Di-Lok chain. The chain could be attached to either a single, forged, staple-like fitting welded to the locally reinforced bottoms of the regular buoys or cut Liberty ship, or to three separate fittings very close together. In either case there would be abrasion as the chains rubbed against each other and, therefore, the heavy chain was chosen to allow for this. The necessity of the three lines coming to a single point on the ship bottom stems from the possibility of an angular oscillation of the platform resulting when the variation of forces in the lines is periodic. A single point of attachment cannot be arranged for the dual orientation buoy unless it were at the very bottom when the buoy was upright. This was not considered desirable because the buoy might then tend to pivot around this point continuously.

The procedure contemplated for laying the mooring would allow it to be done in advance or upon arrival of the platform. The lengths of chain would be attached prior to leaving port and led up on deck and lashed there. It would not be inappropriate to have at least one extra length of chain attached and ready for use later on if one of the mooring lines had to be replaced. If the three legs were set in advance and held temporarily by buoys rented for that purpose, the tug bringing the platform could merely shackle the chain to one line and tow the platform to each of the other two lines in turn and shackle two other chains to them. This would not be

possible without a reasonable amount of slack in each lines, but the slack would not be particular problem if lines 8,400 feet long were used. The tug that set the lines would have to be a fairly large, seagoing type, or even a salvage tug, because it would have to be able to carry the 25,000 feet of line aboard. A fourth leg and an extra anchor or two would probably be taken along also in case some trouble developed. Rather than trying to spot the platform exactly at some particular location, the tug's crew, using the towing winch, could drop the first anchor on sight, take a pull on it to be sure the anchor was properly set, and then make the eye splice in the line at some fixed number of feet from the spot where the vertical line emerged from the water. Thus exact fathometer readings would not have to be depended upon, and the elongation of the line could be taken into account. The other two legs could be set in the same way after the first line were buoyed and the tug could position itself relative to the buoy. That they would not be exactly 120° and some predetermined distance apart would not be critical. Each line would of itself be sufficient to hold the platform, and as long as the three anchor points were well apart and had roughly the same angles between them, there would be sufficient restriction on lateral movement. It would be best to have two legs laid in an easterly direction and the third due west, if possible, because of the prevailing wind direction. This would mean that much of the time two legs would be contributing to the holding of the platform. If the mooring were set when the platform and the tug towing it arrived at the site, the second, larger tug would still be required. This procedure would allow for a more accurate positioning of the three anchors, since the tug actually dropping the anchors could determine its position relative to the smaller tug keeping station where the first anchor was set. Since the cost would be about the same, and the two tugs could together tow the platform more handily, this procedure is recommended. Presumably the Coast Guard would help, after the platform were moored, to fix its exact position and range of lateral movement over a period of time. This would then be used by the FAA and the Coast Guard when they disseminated information concerning the platform for their respective purposes.

The expected forces on the platforms for which this three-leg mooring is intended are not in fact of the same magnitude. As indicated previously, their actual values were estimated more on the basis of judgment than calculation, but the wind forces at least can be calculated with reasonable reliability. The contributions due to the effect of the water motion can be considered as wave forces and current forces. The latter two can have more significant dynamic effects on the platforms than the wind forces, but for design purposes a design static value must be set for each of them. For all three types of forces, the design values must at least reflect the worst situation expected in five years' time.

The writers believe that the wind forces on the relatively low unmanned buoy would at worst (perhaps 120 knots) be about 15,000 pounds. The wave and current forces together should

not exceed more than twice this value because of the shallow draft. Thus of the four platforms, the unmanned buoy would seem to have the best chance of staying moored if the moor itself held. The manned buoy is not appreciably larger above the water than the unmanned buoy because the former lacks a tower, but its greater displacement would mean that the wave forces could become appreciable. A total expected force of perhaps three times as much as for the unmanned buoy does not seem out of line with experimentally obtained values found in the literature for similar-sized vessels. This means the mooring must hold for forces in the range of 150,000 pounds even though these values may be peaks in a continually varying force value. Adding to this the current forces on the mooring lines themselves (which at great depths may be larger than on the surface) provides a situation in which there does not seem to be a very large factor of safety. However, such an eventuality may not occur more than once or twice in the expected period of operation.

The dual orientation buoy could have wind and wave forces as great as those acting on the smaller unmanned buoy, but a much larger current force than any of the four platforms. The combined maximum force, however, should not be much greater than that for the manned buoy.

The cut Liberty ship has considerably more projected area above the water than either of the buoys and the wind forces could conceivably reach 150,000 pounds and greater. Its displacement is also many times greater than any of the buoys, and the wave and current forces could get very large. But it has been grouped with the regular buoys because the total is still less than that for the next three platforms, which are considered together.

4.2. LARGER PLATFORMS

The Liberty ship and the manned and unmanned seadromes differ from the three platforms just considered primarily in size. This means that wind forces as well as those caused by wave action and current could be appreciably larger. The Liberty ship could, in a 120-knot wind, conceivably be acted upon by 300,000 to 400,000 pounds of force. The force on the seadromes would not be as large because of their unitized construction, but a wind force of 150,000 pounds and more would not be out of line in comparison to the other values presented. The wave forces on the seadromes would also be less than those on the Liberty ship because their buoyancy is concentrated so far below the surface. Current forces, on the other hand, might be nearly as large. In any case, the suggested mooring scheme for all three differs from that for the previously discussed three in that a six-leg mooring is considered necessary.

The six mooring lines and their imbedment anchors would be set much as described previously except that all six would be shackled to chains leading from a single mooring buoy. For

the seadromes this buoy would have to be designed so that it could be attached to, and become an integral part of, the center structure of the platform. If it were attached prior to the flooding of the seadrome compartments (in the towing condition) and could be flooded along with them, it could be sufficiently low in the configuration in the moored condition to prevent mooring lines rubbing against the rest of the submerged structure and imposing very large localized loads on them.

The buoy for the Liberty ship moor would also have to be submerged about 30 feet so as to prevent the bow's piercing it, since the ship itself would be attached to the buoy by a single 60- or 70-foot length of 3- or even 4-inch Di-Lok chain. This mooring chain could, under some conditions, become entangled with the chain that attached the nylon lines to the buoy, unless the buoy were built with a lip that extended perhaps ten feet below the bottom of the buoy and tended to keep them apart. Normally the Liberty ship would be streaming downwind from the buoy and there would be no problem. When the ship tended to drift over the buoy, it may also be assumed that the force of the mooring chain on the buoy would be only its weight component and that the chains leading down from the buoy would be nearly vertical.

The submerging of the Liberty ship mooring buoy could probably best be handled by using skin divers and six extra temporary buoys. If most of the permanent elongation were out of the lines when they, with their imbedment anchor assemblies attached, were put in place, it is believed that the buoy could be submerged sufficiently to insure that when the ship were merely drifting and the pull on the buoy was slight, it would remain submerged the required 30 feet. When the pull on the buoy were appreciable, it could well come to the surface because of the elongation of the lines carrying most of the tension, but at such times the ship and buoy could hardly collide. The procedure for submerging the buoy would be initiated after all six lines were in place, roughly 60 degrees apart, and the eye splices were made in each of the lines at the specified locations based on the vertical pull which set the anchors. The upper ends of these lines would be held temporarily by two cables shackled to the eye splice at one end and a buoy at the other. Then one of these cables from each one would be led through vertical holes in the mooring buoy and secured on the deck of the tug, while the other cable and the buoy attached to it supported the mooring line. The smaller tug would be used for bringing each line to the large tug in turn. The mooring buoy would then be flooded and lowered by means of the chain from the Liberty ship until the eye splices in at least several of the nylon lines were in contact with the buoy. The six chains from the buoy would have been lashed to the buoy so that only short lengths with a shackle attached were free, and the skin divers would then shackle several chains to the thimbled eyes. The buoy could then be lowered further and the remaining nylon lines shackled to the remaining chains. When all were shackled the chain lashings would

have to be cut in turn and each line allowed to assume its final orientation. The six temporary cables would be unshackled after the ballast in the buoy had been pumped out and the mooring buoy was in fact supporting the six mooring lines. The windlass of the ship would then take in some length of the mooring chain until only the required 60 or 70 feet was out. Chain stoppers could then be set. Some experimentation with the best length of mooring chain under different wind and sea conditions could be carried out over a period of time by the personnel on the ship, and presumably this best length would be used for the conditions either encountered or expected for each 24-hour period.

There is no doubt that setting the suggested mooring for the Liberty ship would be a hazardous and expensive proposition, and that an extended period of very calm weather would be required. The moorings for the seadromes would be less hazardous, but could also offer considerable difficulty. A six-leg mooring, with lines attached to a floating buoy, could probably also be made to work satisfactorily if the platforms were provided with large outboard motors to allow them to maneuver to avoid the buoys when drifting, or if the buoys were constructed with padding sufficient to preclude their being damaged by the platforms. The latter possibility would be the most economical, but one malfunction could mean the loss of the entire mooring.

4.3. SUBMARINE

The submarine could be moored by the three-leg arrangement described for the three smaller platforms, but allowed to stream from a surface mooring buoy to which the mooring lines were attached. Its bow could be padded and the mooring buoy also padded, so that the possibility of the buoy's destruction would be lessened. The fact that the submarine had an operable propulsion plant, however, would allow it to maneuver so as not to collide with the buoy when drifting. It could also presumably operate its windlass so as to control the chain length between the buoy and the ship.

We believe, however, that the submarine mooring should consist of a single leg. Perhaps two moorings could be set initially, but the ability of the submarine to leave its mooring would obviate the mooring's having to support a very large force. It certainly would not be desirable to have the ship leave for every spell of bad weather, but the design loads could be set considerably under those for either of the other moorings discussed. The single mooring line would have to be nearly vertical to keep lateral movement of the submarine down to a minimum, but with the imbedment anchor this is not a problem.

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5
EVALUATION OF THE PLATFORMS CONSIDERED

While all of the platforms described in a preceding section of this report were shown to be possible mounts for placing VORTAC at sea, the relative merit of one as compared with another

must be considered. This section of the report attempts to do so subjectively with respect to cost and objectively overall.

5.1. COSTS

Table VIII is a summary of the costs of various platforms. Shown in the last two columns are the ratios of first costs and anticipated operating costs for installation of the VORTAC equipment on the different platforms considered as against such installation on the six Coast Guard cutters, exclusive of the cost of the VORTAC equipment itself. The first costs shown in the table for the other platforms also do not include the price of the VORTAC equipment. Further, design and engineering fees are not added, but a 10% increase in the first cost would be adequate to cover the engineering in most cases.

A brief summary of the estimated first cost of each of the platforms is as follows:

Liberty Ship	
Hull Modification Material	$ 58,000
Hull Modification Labor	42,000
Overhead	29,000
Subtotal	$129,000
7 1/2% Profit	10,000
Basic Cost	$139,000
Drydocking (including tugs, etc.)	10,000
New Machinery	204,000
Outfitting and Accommodations	153,000
Total First Cost	$506,000

Cut Liberty Ship	
Hull Modification Material	$ 18,000
Hull Modification Labor	35,000
Overhead	25,000
Subtotal	$ 78,000
7 1/2% Profit	6,000
Basic Cost	$ 84,000
Drydocking (including tugs, etc.)	42,000
New Machinery	204,000
Outfitting and Accommodations	153,000
New Ends	112,000
Total First Cost	$595,000

TABLE VIII. COST SUMMARY

Item	Platform Cost	Mooring Cost	Total First Cost	Operating Cost/year	Relative First Cost Compared to Coast Guard	Relative Operating Cost Compared to Coast Guard
Liberty Ship	$ 506,000	$450,000	$ 956,000	$259,850	0.96	2.88
Cut Liberty	595,000	259,800	854,800	257,350	0.85	2.88
Manned Buoy	1,055,000	259,800	1,314,800	257,350	1.31	2.88
Trawlers (two)	500,000	0	500,000	311,700	0.50	3.50
Unmanned Buoy	278,000	259,800	537,800	100,000	0.54	1.12
Unmanned Seadrome	1,183,000	450,000	1,633,000	100,000	1.63	1.12
Manned Seadrome	1,766,900	450,000	2,216,900	257,350	2.22	2.88
Submarine	100,000	210,000	310,000	339,600	0.360	3.80
Dual Orientation Buoy	672,800	259,800	932,600	100,000	0.93	1.12

Manned Buoy	
Material	$ 55,000
Labor	83,000
Overhead	58,000
Subtotal	$ 196,000
7 1/2% Profit	15,000
Basic Cost	$ 211,000
Machinery	204,000
Outfitting and Hull Engineering	150,000
Accommodations	490,000
Total First Cost	$1,055,000

Small Operating Ship (two)	
Purchase Price	$225,000
Modification	25,000
Total First Cost	$250,000

Unmanned Buoy	
Material	$ 19,000
Labor	32,000
Overhead	22,000
Subtotal	$ 73,000
7 1/2% Profit	6,000
Basic Cost	$ 79,000
Machinery	136,000
Outfitting and Hull Engineering	64,000
Total First Cost	$ 278,000

Unmanned Seadrome	
Material	$ 259,600
Labor	434,500
Overhead	216,700
Subtotal	$ 909,100

7 1/2% Profit	68,200
Basic Cost	$ 978,100
Machinery	148,900
Outfitting and Hull Engineering	56,000
Total First Cost	$1,183,000

Manned Seadrome	
Material	$ 259,600
Labor	434,500
Overhead	216,700
Subtotal	$ 909,100
7 1/2% Profit	68,200
Basic Cost	$ 978,100
Machinery	148,900
Outfitting and Hull Engineering	150,000
Accommodations	490,000
Total First Cost	$1,766,900

Submarine	
Purchase Price	$ 0
Modification	100,000
Total First Cost	$100,000

Dual Orientation Buoy	
Material	$107,000
Labor	194,000
Overhead	136,000
Subtotal	$437,000
7 1/2% Profit	32,800
Basic Cost	$469,800
Machinery	136,800
Outfitting and Hull Engineering	67,000
Total First Cost	$672,800

It has been assumed that the Liberty ship could be obtained free of charge. This is reasonable if an argument can be made that the platform will contribute to national defense. If the ship could not be obtained cost-free, the first cost shown in the table would go up by $50,000, the current scrap price of a Liberty ship. Since only sketchy information was available on the seadromes, these costs are probably less certain than the others. Rather than showing the cost of a specially built ship, the table only includes the estimated cost of two used trawlers or similar ships. Although the Coast Guard requires more than two ships to man one ocean station, it is believed that two ships would be adequate for this purpose if they did not have additional missions. Also, because it is assumed that the ships would be in service for only five years, they would not require any major overhauls. In all the other cases it has been assumed that only one platform was necessary, and that it could remain on station for five years. Major overhauls would then not be feasible in the period. The first cost of the submarine includes no value for the purchase price.

The mooring costs in the table include the estimated prices of the nylon mooring lines and imbedment anchors, the price for temporary use of buoys when needed or fabrication costs for permanent buoys, and the charter fees for appropriate tugs and crews to tow the platforms and set the mooring. For the larger platforms it was assumed that both tugs would be needed for five weeks, but only four weeks were allowed for the smaller platforms and the submarine.

In all cases operating costs cover the cost of two crews. Since the crews' wages are the largest part of the operating cost these costs are very dependent upon the values assumed for salaries and wages. For the Liberty ship, cut Liberty ship, manned buoy, and manned seadrome the following schedule was assumed:

1 Master	$ 18,200/year
1 Chief Engineer	16,700
2 Engine Utility Men	19,600
2 Electronic Technicians	26,000
1 Cook	9,500
1 Chief Electrician	16,700
	$106,700
Plus 10% bonus	$117,400

Included in these values are fringe benefits. The 10% bonus is an attempt to account for paying a premium which the writers believe would be necessary.

In the case of the trawler, it was assumed that the crew would be paid in accordance with the wages in the fishing and coastal-shipping industries. These wages are lower than the union wages which are the basis for the figures on the Liberty ship and other platforms. Officers were assumed to average $10,000 a year and the men $7,000 a year. Three electronic technicians were included at the same rate as for the Liberty ship. Thus the crew costs for the trawler, because of the lower pay scale, are not twice the Liberty ship costs, despite about twice the number of men aboard. The main justification for the lower pay scale is that the trawler would be operated as a ship and that a crew could be obtained on the same basis as for any other ship of the same type.

The costs for the submarine were based on the same wage scale as for the Liberty ship. Since the submarine was assumed to have propulsion capability, extra men have been assumed to be aboard. For the table the submarine crew was assumed to total twelve men. Four extra men would not be enough to operate it on a continuous basis, but they would be enough to operate it on a need basis. It would be possible to put aboard additional men temporarily for the purpose of taking the ship out to the station.

The following additional costs have been included in estimating the operating cost of the Liberty ship. In general these are representative of the values for the other platforms:

Fuel	$ 7,300/year
Insurance	None
Maintenance and Repair	5,750/year
Subsistence	10,000/year
Stores and Supplies	2,000/year

5.2. OVERALL EVALUATION TABLE AND DISCUSSION

Table IX presents the writers' rating of the platforms which were considered for placing VORTAC at Ocean Station Charlie. The bottom line indicates the evaluation of the various proposals in descending order of their value. That is, installation on the Coast Guard ships is considered to be the best overall method, and the manned seadrome is considered to be the poorest. The evaluation is not accurate enough to indicate truly the degree of preference, and thus only the order of preference should be noted quantitatively. By changing the weight factors in column 1 the order of preference could undoubtedly be changed. These factors indicate the writers' estimate of the relative importance of the items included, but may not agree with that of the Federal Aviation Agency. By assigning new values to the items in column 1 the reader could make his own evaluation. This would be done by multiplying column 1 by each of the other columns and adding down. For instance, the relative importance of first cost and operating cost to the FAA may not be equal, as the table shows them to be.

TABLE IX. OVERALL EVALUATION

Item	Weight** Factor	Coast Guard	Trawlers	Unmanned Buoy	Dual Orientation Buoy	Submarine	Unmanned Seadrome	Manned Buoy	Cut Liberty	Liberty Ship	Manned Seadrome
Safety	29.0	1.0	1.1*	1.8	1.8	1.6	1.8	2.0	2.2	2.0	2.0
Degree of Uncertainty	26.1	1.0	1.0	2.1	2.1	1.5	2.2	1.8	1.9	2.1	2.1
First Cost	14.5	1.0	0.5	0.54	0.93	0.31	1.63	1.31	0.85	0.96	2.22
Operating Cost	14.5	1.0	3.5	1.12	1.12	3.8	1.12	2.88	2.88	2.88	2.86
Time Inoperative	8.7	1.0	1.0	1.3	1.3	1.1	1.3	1.1	1.0	1.0	1.0
Ease of Maintenance	5.8	1.0	1.0	1.4	1.4	1.2	1.3	1.1	1.0	1.0	1.0
Antenna Development	1.4	1.0	1.0	1.0	1.0	1.2	1.0	1.1	1.0	1.0	1.0
Relative Weight	100.0	100.0	132.0***	152.0	158.0	163.0	170.0	183.0	183.0	184.0	203.0

* All relative values are based on the Coast Guard installation having a value of 1.0.

** The weight factors are given in percent.

*** Obtained by multiplying column 1 by column 3, adding down, and rounding to the nearest whole number.

Briefly, the meaning of the items in the first column are as follows:

Safety. Safety is intended to indicate the degree of probability of personnel being killed or seriously injured. All of the moored platforms would require changing the crew periodically. This means that eight men would have to leave the ship (presumably a Coast Guard cutter) which brings them out and go aboard the platform. Those men already there would transfer back to the ship. On the average, this would happen once a month and involves a risk which men who stay aboard a ship do not take. In the case of the unmanned platforms, men must go aboard no less than once a week; however, there are fewer men and a more elaborate means for accomplishing the transfer might be provided. This would also involve an additional risk which men who stay aboard a ship do not take. Also considered in assigning the values for safety was the probability of the platform's breaking away from its mooring. Finally, other factors, such as stability, were included to give an overall relative rating.

Degree of uncertainty (ignorance factor). This row indicates the relative uncertainty of design in the various proposals. For instance, it is known that the Coast Guard installation would operate. Hence there is confidence that installing VORTAC equipment on a Coast Guard cutter would give the desired result. All of the other platforms contained design problems which would require development and testing before they could be satisfactorily solved. The degree of uncertainty can also be interpreted as the degree of pioneering. Since no one has yet moored for long periods in deep water, the certainty of all of the moored platforms would depend on the ability of the mooring to remain intact for five years.

First cost and operating cost. These two items have been discussed previously. The factors in Table IX were obtained by dividing the costs in Table VIII by the values shown for the Coast Guard installation.

Time inoperative. All of the platforms are believed to have high enough reliability to make them worth considering. Those with the antenna close to the water would have more of a problem with sea water on the antenna. Therefore it is assumed that these might show more frequent outages. The unmanned platforms might not show more frequent outages than the Coast Guard, but they might be for longer periods. In rough weather it might not be possible to board the platform, and hence it might have to remain inoperative until the weather abates.

Ease of maintenance. This row indicates the accessibility and convenience of maintaining the VORTAC equipment and generating plant. One reason for placing the Coast Guard at 1.0 is that the FAA personnel would not have to maintain the electrical plant, since the Coast Guard cutter engine-room force already performs this function.

Antenna development. It would be advisable to redesign the antenna to fit the VORTAC sea application. However, most of the platforms could use the existing antennas, with a redesigned plastic support for the TACAN antenna. In the case of the submarine and manned buoy it is believed that antenna redesigning would be necessary.

Table IX indicates that when all of these factors are considered, the Coast Guard installation is the best. This assumes that the Coast Guard is willing to cooperate with the FAA. If for good reasons the Coast Guard were unwilling to provide the necessary service or to alter their ships, then it would be necessary to choose one of the other methods. As indicated, the next choice would be the trawlers. This choice would provide nearly all the advantages of the Coast Guard installation in addition to others, such as freedom of location. The ships would have some resale value, which the alterations to the Coast Guard cutters would preclude. The one major disadvantage of the trawlers would be the high operating cost.

If the FAA were willing to develop the VORTAC equipment to increase its reliability, the unmanned buoy would become a strong contender. It rates lower than the two ships mainly because of the necessity of frequently transfering personnel to the platform for maintenance and repair. Because it would be smaller than the other moored platforms and would be unmanned, the unmanned buoy would present much less critical mooring problems. The consequences of its possibly going adrift would not be so serious as for the manned platforms. It would not be likely to go adrift when the maintenance crew were aboard since they would normally stay aboard the Coast Guard cutter in excessively bad weather.

The principal advantage of the submarine is that it would have propulsion capability, although it would be moored. This would give it a factor of safety which the other moored platforms would not have. It would also not require towing to the site. Its disadvantages would be unknown availability, unpleasant motion for the crew, and antenna water problems.

Because of its size the seadrome would have essentially the same mooring problems as the Liberty ship. The unmanned version would have the personnel transfer problems of the unmanned buoy. All of the manned platforms rate low because of the large weight given to safety. The large platforms are especially poor because of the difficulties in installing a permanent moor.

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6
RECOMMENDATIONS

The following recommendations are made on the basis of this study:

(a) So long as it is assumed that presently available VORTAC equipment must be utilized, it is recommended that the Coast Guard cutters be used to mount VORTAC at Ocean Station Charlie. This judgment assumes that only one location will be established and that Ocean Station Charlie is satisfactory. It is obvious that if VORTAC were to be placed at a location not normally manned by the Coast Guard, some other method would have to be used. On the other hand, if a chain of stations, say ten, were desired, probably one of the platforms other than the Coast Guard installation would be preferable. The writers have not considered this aspect of the problem.

(b) It is recommended that the VORTAC equipment be redesigned to improve its reliability. If the FAA were to do this, then it is believed that the unmanned buoy could be the preferred platform. The unmanned buoy would be favored by multiple-station installation (the chain of stations).

(c) If the Coast Guard were to decide that it could not accommodate the VORTAC equipment and technicians, it is recommended that two trawler-type ships be used. Once again we assume that presently available equipment would be used.

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